Low Mineral Intake Is Associated with High Systolic Blood Pressure in the Third and Fourth National Health and Nutrition Examination Surveys

Could We All Be Right?

Marilyn S. Townsend, Victor L. Fulgoni III, Judith S. Stern, Seth Adu-Afarwuah, and David A. McCarron

Analysis of the first National Health and Nutrition Examination Survey (NHANES) in 1984 revealed that a dietary pattern low in mineral intake, specifically calcium, potassium, and magnesium, was associated with hypertension in American adults. Using more recent survey data from NHANES III and NHANES IV, we re-examined the validity of this relationship. Blood pressure (BP) and nutrient intake data from 10,033 adult participants in NHANES III and 2311 adults in NHANES IV revealed findings similar to those of the earlier analysis, demonstrating that the association between inadequate mineral consumption and higher BP is valid and has persisted over two decades. Exploring this relationship further, we separated untreated hypertensive persons by hypertension type (systolic, diastolic, or both), and observed that the BP effect of low mineral intake was most pronounced in those with only systolic hypertension. We also observed that sodium intake was significantly lower in the systolic hypertension group and significantly higher in the diastolic hypertension group compared with the other groups. The nutrient pattern in the combined hypertension group was similar to that of the normotensive group. These findings may help to explain the inconsistent responses generally observed in dietary intervention studies, and they highlight the possible importance of tailored nutritional recommendations for hypertension based on hypertension category and individual dietary practices. Although randomized controlled trials are needed to characterize further the relationship between nutrient intake and hypertension type, these findings indicate that dietary management of hypertension may be more effective if the focus is on the overall nutritional profile rather than single-nutrient intake as currently recommended for most patients. Am J Hypertens 2005;18:261–269 © 2005 American Journal of Hypertension, Ltd.

Key Words: Blood pressure, diet, systolic hypertension, NHANES.

An analysis of the First National Health and Nutrition Examination Survey (NHANES I) published in 1984[1] identified inadequate dietary intakes of calcium and potassium as the mineral/electrolyte pattern that best predicted the presence of hypertension, particularly high systolic pressure, in adults. Among Americans, a diet containing adequate intakes of dairy foods, fruits, and vegetables (similar to what has subsequently been labeled the DASH diet[2]), was associated with the lowest blood pressure (BP) in NHANES I. Numerous population surveys have confirmed the beneficial impact of dietary calcium, as a surrogate for adequate mineral intake, on BP levels in general[3] and most consistently on systolic BP.[4]

In the 1984 analysis of NHANES I, higher levels of dietary sodium were not related to higher BP.[1] As noted in that report, the NHANES I data suggested the reverse, ie, BP tracked inversely with dietary sodium. Analyses by others confirmed the findings that not only lower calcium but also lower sodium intake was linked to higher BP in NHANES I.[5] Similar observations have been reported

Received September 29, 2003. First decision November 25, 2003. Accepted September 20, 2004.

From the University of California (MST, JSS, SA-A, DAMC), Davis, California; and Nutrition Impact LLC (VLF), Battle Creek, Michigan.

This work was supported by an education grant from Dairy Management Inc., Rosemont IL.

Address correspondence to Dr. David A. McCarron, Academic Network, 1221 SW Yamhill, Suite 303, Portland, OR 97205-2110; e-mail: dmccarron@academicnetwork.com

Published by Elsevier Inc.

0895-7061/05/$30.00
doi:10.1016/j.amjhyper.2004.09.017

Table 1. Exclusion criteria for NHANES III and IV samples

	NHANES III (n = 20,050)	NHANES IV (n = 4706)
Age <20 years	1225	262
Age >75 years	2507	493
Unreliable diet record	1994	171
Pregnant	152	249
Missing BP value	26	82
Abnormal BP value*	8	43
Diabetes mellitus	1072	330
Currently taking insulin	0	1
High BP ever diagnosed	3033	764
Currently taking hypertension medication	0	0
Total number excluded	10,017	2,395
Total sample size	10,033	2,311

BP = blood pressure; NHANES = National Health and Nutrition Examination Survey.
Data are absolute numbers.
* Abnormal BP defined as systolic <80 mm Hg or diastolic <40 mm Hg.

from epidemiologic surveys.[6,7] Randomized trials have also confirmed a BP-lowering effect of adequate mineral consumption from foods and from supplements.[2,8–10] However, although BP responses to increased mineral intake vary among individuals, the effect is typically greater when foods are the mineral source.[2,8,9,11] This suggests that the combination of naturally occurring nutrients in foods contributes to the BP-lowering effect.

The 1984 NHANES I analysis revealed that inadequate levels of mineral intake was the nutrient profile that best predicted hypertension risk in adults. We hypothesized that this relationship continues to exist and would be observed again in more recent dietary survey data. Using NHANES III (1989 to 1991 and 1991 to 1994) and NHANES IV (1999 to 2000), we examined the relationship between the intake of dietary nutrients and BP levels in American adults. We extended the analysis to explore whether sodium intake or BP category influenced this relationship.

Methods

National Surveys

As with the previous surveys, NHANES III and IV were designed to obtain a representative sample of the population in the United States using a complex, stratified, multistage probability cluster sampling design.[12,13] The surveys consisted of partial probability samples of households in the 48 contiguous states. Institutionalized and homeless persons were not included. The NHANES III study was designed to be nationally representative for either 3 or 6 years of data collection, whereas NHANES IV was designed to give an annual sample that is nationally representative.

In both surveys, adults responded to survey questions in home interviews. Interviewees were subsequently examined in the Mobile Examination Center (MEC) in examinations lasting approximately 3 h. A modified home examination was offered to a limited number of adults ≥60 years of age who could not come to the MEC. Both surveys over-sampled adults ≥60 years, Mexican Americans, and African Americans to produce more reliable estimates for these groups. For this study, only adults examined in the MEC or at a modified home examination were included. The Institutional Review Board of the University of California at Davis reviewed the protocol for this study.

Sample

The NHANES III data sets from 1989 to 1991 and 1991 to 1994 were combined (39,695 individuals) to achieve sufficient sample sizes for adults-only population subgroups (n = 20,050) and then for adults with reliable dietary data (n = 18,056). Although there was no upper age limit in NHANES III, we opted to use 75 years of age, similar to the upper limit of 74 years used by McCarron et al[1] for NHANES I, to enhance comparability of results. A final sample was generated to meet the following criteria: age 20 to 75 years, not pregnant, and not lactating. As reported for the previous article,[1] we excluded persons who were currently taking medications for high BP or diabetes or who had been told by a physician that they had hypertension or diabetes (Table 1). Given that our analyses were restricted to individuals without hypertension and the higher risk of hypertension among non-Hispanic individuals of African American ethnicity, we eliminated a disproportionate number of non-Hispanic African Americans from the original sample.

For NHANES IV, the two annual data sets were combined (9650 individuals), producing an adults-only sample of 4706 with an examination at the MEC. A final sample was generated to meet the same criteria mentioned above. Comparable percentages of participants in both NHANES III and IV were excluded based on a prior history of

Table 2. Characteristics of NHANES III and IV cohorts

	NHANES III			NHANES IV		
Characteristic	Normotensive (*n* = 8988)	Hypertensive* (*n* = 1045)	*P* value†	Normotensive (*n* = 2012)	Hypertensive* (*n* = 299)	*P* value†
Sex (% male/ female)	48/52	63/37		50/50	55/45	
Ethnicity (% African American)	10	13		9	12	
Age (y)	38.5 ± 0.4	53.7 ± 0.8	<.0001	38.5 ± 0.3	51.1 ± 1.1	<.0001
BMI (kg/m²)	25.4 ± 0.1	27.9 ± 0.3	<.0001	26.7 ± 0.2	29.2 ± 0.5	<.0001
Systolic BP (mm Hg)	114.5 ± 0.2	145.2 ± 0.6		114.5 ± 0.3	145.9 ± 1.1	
Diastolic BP (mm Hg)	71.7 ± 0.2	85.1 ± 0.5		71.3 ± 0.2	85.3 ± 1.0	
Energy (kcal)	2298 ± 21.4	21.95 ± 48.7	.022	2295 ± 29.0	2269 ± 79.0	
Protein (gm)	85 ± 1.1	83 ± 2.1		84 ± 1.2	87 ± 3.2	
Carbohydrate (g)	279 ± 2.9	262 ± 6.8	.006	287 ± 3.9	269 ± 10.2	
Total fat (g)	88 ± 1.2	85 ± 2.7		84 ± 1.3	84 ± 3.6	
Dietary fiber (g)	17 ± 0.2	17 ± 0.5		16 ± 0.3	15 ± 0.8	
Alcohol (g)	12 ± 0.7	12 ± 1.7		12 ± 1.2	17 ± 4.7	
Sodium (mg)	3686 ± 44.4	3600 ± 122.0		3589 ± 51.5	3613 ± 147.2	
Calcium (mg)	860 ± 12.5	802 ± 32.2	.047	880 ± 19.2	788 ± 44.5	
Potassium (mg)	2919 ± 26.7	2863 ± 69.1		2781 ± 38.0	2749 ± 98.3	
Magnesium (mg)	309 ± 3.0	304 ± 8.4		295 ± 4.7	287 ± 10.8	
Phosphorus (mg)	1346 ± 13.4	1305 ± 33.4		1350 ± 18.4	1337 ± 48.2	
Iron (mg)	16 ± 0.2	16 ± 0.5		16 ± 0.3	15 ± 0.6	
Vitamin C (mg)	105 ± 2.1	111 ± 9.4		96 ± 2.7	85 ± 6.0	
Vitamin E (AE)	10 ± 0.2	10 ± 0.5		10 ± 0.3	9 ± 0.5	
Vitamin A (AE)	999 ± 17.7	1245 ± 149.2		963 ± 37.7	909 ± 78.9	
K+Ca+Mg (mmol)	109 ± 1.0	106 ± 2.6		105 ± 1.5	101 ± 3.6	
Na:K (mmol: mmol)	2.3 ± 0.0	2.3 ± 0.1		2.4 ± 0.03	2.4 ± 0.1	

Abbreviation as in Table 1.
Data are unadjusted means ± standard error.
* Hypertensive defined as systolic blood pressure ≥ 140 mm Hg, or diastolic blood pressure ≥ 90 mm Hg, or both.
† *P* value indicated where significant difference was found between hypertensive and normotensive groups.

hypertension or diabetes (Table 1). In total, approximately 50% of the participants in both NHANES III and IV met the inclusion criteria, resulting in final samples of 10,033 and 2311 respectively.

Nutrient Variables

We selected dietary factors commonly thought to influence BP by either direct or indirect means. Previous research was the basis for selection of two combination variables: the combined mineral intake variable (potassium + calcium + magnesium) and the sodium/potassium ratio variable.[2,9,11] Those nutrients and nutrient variables are identified in Table 2.

Measurements

The average of BP measurements during the household interview ($n = 3$) and MEC examination ($n = 2$) were used in NHANES III. For NHANES IV, the average BP reported to the examinee was used. For nutrient consumption, 24-h dietary recalls were analyzed for energy, protein, carbohydrates, total fat, dietary fiber, and the micronutrients calcium, potassium, magnesium, sodium, phosphorus, iron, and vitamins C, E, and A. Calcium, potassium, and magnesium were combined for a mineral variable, and the sodium-to-potassium ratio was calculated. Hypertension categories were defined as follows: 1) systolic pressure ≥140 mm Hg, also referred to as isolated systolic hypertension; 2) diastolic pressure ≥90 mm Hg, also referred to as diastolic hypertension; and 3) systolic and diastolic pressures ≥140 and ≥90 mm Hg, respectively, also referred to as combined hypertension and high mean arterial BP.

Statistical Analysis

Analyses were performed with the Statistical Analysis System, release 8.1 for Windows (SAS Institute, Cary, NC). Appropriate statistical weights were used to adjust for over-sampling of some groups and for nonresponse of some individuals in NHANES III (WTPFHX6) and NHANES IV (WTMEC2YR). Means and standard errors were calculated for the total sample and for the four BP subgroups for demographic characteristics, BP, and macro- and micronutrients. Regression analysis was used to examine differences between groups. Finally, multivariate regression was used to determine whether unadjusted effects remained after adjusting for age, sex, ethnicity, body mass index (BMI), alcohol, and energy intake. Differences were considered significant at values of $P < .05$.

Results

Table 2 compares the unadjusted nutrient profile and population characteristics for the normotensive compared with newly diagnosed hypertensive participants in NHANES III and IV. In both surveys, participants with hypertension differed significantly from normotensive persons in age and body mass index (BMI) (all $P < .0001$). The mean age of the hypertensive group was approximately 15 years older than that of the normotensive group in NHANES III and 5 years older in NHANES IV. The BMI were approximately 2.5 kg/m^2 larger in the hypertensive groups compared with the normotensive groups in both surveys. Reported calcium intake was significantly lower in hypertensive persons in NHANES III ($P < .05$) and marginally lower in NHANES IV ($P = .052$). Intakes of sodium, potassium, magnesium, phosphorus, protein, fat, carbohydrate, and alcohol did not differ between normal and hypertensive participants in either survey.

Tables 3 and 4 show the nutrient intakes of participants by category of BP: normal, systolic, diastolic, and both systolic and diastolic hypertension. Participants with isolated systolic hypertension made up approximately 60% of the hypertensive population, and this group was significantly older than the normotensive and the other hypertensive groups (Table 3). Compared with the normotensive and isolated systolic hypertension groups, the diastolic hypertension group was predominantly male (86%). The diastolic hypertension–only and the combined hypertension groups were more likely to be of non-Hispanic African American ethnicity and to have higher BMI.

Very importantly, the pattern of significantly lower mineral intake (potassium + calcium + magnesium) emerged as unique to persons with isolated systolic hypertension in both NHANES III (Table 3) and NHANES IV (Table 4). This pattern was not observed among the diastolic and combined hypertension groups. Consistent with a dietary pattern of deficiencies rather than excesses, the isolated systolic hypertension group also exhibited significantly lower intakes of energy, protein, carbohydrate, fat, and fiber in NHANES III. Lower intakes of energy and carbohydrate were also evident in NHANES IV.

Of note, dietary sodium intake was also significantly lower in both NHANES III and IV in persons with isolated systolic hypertension compared with the normotensive participants (3257 mg/day *v* 3686 mg/day, NHANES III; 3171 mg/day *v* 3584 mg/day, NHANES IV). Sodium intake was significantly higher in the group with isolated diastolic hypertension compared with the normotensive group (4298 mg/day *v* 3584 mg/day, NHANES IV). Participants with both elevated systolic and diastolic pressures exhibited a nutritional pattern similar to those with normal BP. The BMI was significantly greater in the groups with diastolic hypertension and combined systolic and diastolic hypertension compared with the normotensive and isolated systolic hypertension groups (NHANES IV).

When adjusted for age, sex, ethnicity, BMI, alcohol, and energy intake, the significant reductions in the combined mineral variable (potassium, calcium, and magnesium intakes) persisted in the NHANES IV cohort of participants with isolated systolic hypertension (data not shown). In NHANES III, the multivariate adjustment eliminated the significantly lower calcium intake. The adjustment for age accounted for the major impact on calcium intake in the isolated systolic hypertension participants. Of the macronutrient differences observed in the initial analysis, the lower fiber intake remained significant for the isolated systolic hypertension participants in the NHANES III cohort after adjusting for potential confounding variables (data not shown).

Discussion

This parallel analysis of nutrient intake and BP status from the two most recent NHANES databases of the National Center for Health Statistics supports a variety of previous observations related to diet and BP regulation. In addition, it provides a potentially critical new insight regarding the sodium–BP relationship. Our analyses confirm once again that inadequate mineral intake (calcium, potassium, and magnesium) is the dietary pattern that best predicts elevated BP in persons at increased risk for cardiovascular disease—those with isolated systolic hypertension. Furthermore, the data indicate that this pattern has persisted across three decades of federally sponsored NHANES surveys and thus is clearly not simply a fleeting trend in the United States. Instead, this observation represents a consistent pattern of dietary intake, one characterized by low intakes of dairy products, fruits, and vegetables.

The association between low mineral intake (calcium,

Table 3. Characteristics of NHANES III Cohort by blood pressure (BP) status

	Normotensive			**Hypertensive***			
	(*n* = 8988)	**Systolic (*n* = 620)**	***P* value†**	**Diastolic (*n* = 212)**	***P* value**	**Combination (*n* = 213)**	***P* value†**
Sex (% male/female)	48/52	52/48		86/14		68/32	
Ethnicity (% African American)	10	9		18		19	
Age (y)	38.5 ± 0.4	61.2 ± 0.9	<.0001	38.9 ± 0.9		49.5 ± 1.1	<.0001
Body mass index (kg/m^2)	25.4 ± 0.1	26.9 ± 0.4	.0003	29.1 ± 0.4	<.0001	29.2 ± 0.9	<.0001
Systolic BP (mm Hg)	114.5 ± 0.2	148.6 ± 0.5		130.2 ± 0.5		152.3 ± 1.2	
Diastolic BP (mm Hg)	71.7 ± 0.2	78.5 ± 0.4		92.7 ± 0.3		95.5 ± 0.5	
Energy (kcal)	2298 ± 21.4	1986 ± 67.6	<.0001	2630 ± 103.4	.0025	2297 ± 133.2	
Protein (g)	85 ± 1.1	74 ± 2.3	<.0001	97 ± 4.4	.014	94 ± 5.9	
Carbohydrate (g)	279 ± 2.9	242 ± 10.5	.0004	310 ± 16.0		265 ± 15.9	
Total fat (g)	88 ± 1.2	76 ± 2.8	<.0001	102 ± 6.0	.030	90 ± 7.1	
Dietary fiber (g)	17 ± 0.2	16 ± 0.5	.029	19 ± 1.2		18 ± 1.8	
Alcohol (g)	12 ± 0.7	10 ± 2.1		18 ± 3.6		12 ± 3.2	
Sodium (mg)	3686 ± 44.4	3257 ± 156.2	.007	4117 ± 226.5		3989 ± 314.5	
Calcium (mg)	860 ± 12.5	764 ± 44.2	.023	896 ± 71.8		801 ± 56.6	
Potassium (mg)	2919 ± 26.7	2707 ± 81.0	.007	3043 ± 144.5		3105 ± 188.0	
Magnesium (mg)	309 ± 3.0	285 ± 9.9	.015	337 ± 16.6		322 ± 22.4	
Phosphorus (mg)	1346 ± 13.4	1185 ± 43.8	.0003	1509 ± 78.9	.044	1414 ± 95.2	
Iron (mg)	16 ± 0.2	14 ± 0.6	.021	17 ± 1.0		18 ± 1.8	
Vitamin C (mg)	105 ± 2.1	104 ± 14.2		116 ± 9.5		127 ± 16.3	
Vitamin E (AE)	10 ± 0.2	9 ± 0.5		12 ± 1.6		10 ± 1.1	
Vitamin A (AE)	999 ± 17.7	1222 ± 156.7		965 ± 195.3		1632 ± 477.1	
Ca + K+ Mg (mmol)	109 ± 1.0	100 ± 3.5	.009	114 ± 5.6		113 ± 6.7	
Na:K (mmol:mmol)	2.3 ± 0.0	2.1 ± 0.1	.0006	2.5 ± 0.1		2.4 ± 0.1	

Abbreviation as in Table 1.

Data are unadjusted means ± standard error.

* Hypertensive is defined as systolic BP ≥ 140 mm Hg, diastolic BP ≥ 90 mm Hg, or combination of both.

† *P* value indicated where significant difference is found between hypertensive and normotensive groups.

Table 4. Characteristics of NHANES IV Cohort by blood pressure (BP) status

	Normotensive			Hypertensive*			
	(*n* = 2012)	Systolic (*n* = 174)	*P* value†	Diastolic (*n* = 50)	*P* value†	Combination (*n* = 75)	*P* value†
Sex (% male/female)	50/50	44/56		74/26		57/43	
Ethnicity (% African American)	9	12		15		10	
Age (y)	38.7 ± 0.3	58.0 ± 1.5	<0.0001	40.2 ± 1.5		50.2 ± 2.1	<0.0001
BMI (kg/m^2)	26.7 ± 0.2	27.9 ± 0.6		31.5 ± 1.1	<0.0001	29.2 ± 0.9	0.009
Systolic BP (mm Hg)	114.5 ± 0.3	149.5 ± 0.9		128.2 ± 1.0		156.4 ± 2.0	
Diastolic BP (mm Hg)	71.3 ± 0.2	74.5 ± 1.1		92.9 ± 0.5		97.4 ± 1.0	
Energy (kcal)	2292 ± 29.2	2057 ± 92.6	0.016	2532 ± 186.9		2371 ± 155.3	
Protein (g)	84 ± 1.2	78 ± 4.0		100 ± 7.5	0.030	89 ± 6.0	
Carbohydrate (g)	287 ± 3.9	246 ± 11.3	0.0006	299 ± 25.3		277 ± 20.6	
Total fat (g)	84 ± 1.3	77 ± 4.6		98 ± 8.8		83 ± 5.9	
Dietary fiber (g)	16 ± 0.3	15 ± 1.1		15 ± 1.3		16 ± 1.6	
Alcohol (g)	12 ± 1.2	14 ± 3.7		11 ± 3.5		28 ± 14.4	
Sodium (mg)	3584 ± 51.6	3171 ± 156.6	0.012	4298 ± 346.0	0.042	3708 ± 307.6	
Calcium (mg)	880 ± 19.1	700 ± 37.0	<0.0001	906 ± 142.8		834 ± 67.1	
Potassium (mg)	2782 ± 38.2	2520 ± 114.5	0.031	2960 ± 214.3		2932 ± 223.4	
Magnesium (mg)	295 ± 4.7	272 ± 13.7		289 ± 20.4		309 ± 24.8	
Phosphorus (mg)	1349 ± 18.5	1196 ± 53.3	0.007	1526 ± 129.4		1400 ± 84.1	
Iron (mg)	16 ± 0.3	14 ± 0.8		15 ± 1.1		15 ± 1.2	
Vitamin C (mg)	97 ± 2.7	85 ± 8.4		78 ± 11.0		91 ± 12.6	
Vitamin E (AE)	10 ± 0.3	9 ± 0.7		9 ± 0.8		10 ± 1.3	
Vitamin A (AE)	968 ± 38.0	903 ± 139.2		985 ± 129.5		851 ± 99.2	
Ca + K + Mg (mmol)	105 ± 1.5	93.1 ± 4.0	<0.005	110 ± 8.8		109 ± 7.6	
Na:K (mmol:mmol)	2.4 ± 0.0	2.3 ± 0.1		2.7 ± 0.2		2.4 ± 0.2	

Abbreviation as in Table 1.

Data are unadjusted means ± standard error.

* Hypertensive is defined as systolic BP ≥140 mm Hg, diastolic BP ≥ 90 mm Hg, or combination of both.

† *P* value indicated where significant difference was found between hypertensive and normotensive groups.

potassium, and magnesium) and increased hypertension risk for persons with isolated systolic hypertension has continued in the presence of federal policy and guidelines that, until very recently, emphasized excessive dietary sodium chloride as the sole nutritional issue in preventing and managing high BP.[14] As first noted in the initial NHANES analysis,[1] and then by others,[5,6] higher dietary sodium intake is not associated with higher BP in cross-sectional studies among American adults. Our data indicate just the opposite for persons at greatest cardiovascular risk, namely, those with isolated systolic hypertension.[14] Sodium intake is lower for those with isolated systolic hypertension compared with normotensive participants. In fact, our data from NHANES I, III, and IV (1999 to 2000) show that the hypertensive category (NHANES I) and isolated systolic hypertensive category (NHANES III and IV) have significantly lower sodium intakes compared with normotensive participants. In contrast, individuals with elevated diastolic BP who also had higher mean BMI tended to report sodium intakes greater than those of normotensive persons ($P < .042$, NHANES IV) and significantly higher sodium intakes than those of individuals with isolated systolic hypertension (data not shown).

The negative association of minerals (potassium, calcium, magnesium) to isolated systolic hypertension did not persist in the multivariate analyses controlling for potential confounding variables. Although age is a primary factor influencing hypertensive states, there are one or more characteristics of older study participants that cause their BP to be higher. Diet could certainly be that factor in part. This does not mean that mineral intakes are not important. In fact, evidence from the DASH trial shows that they are important for BP control.[2,10] Because of our sample size and statistical power, we could not stratify by age, gender, or ethnicity. However, our three-category approach for BP and stratification by these variables would be beneficial in future work. Another finding among those with isolated systolic hypertension, the lower fiber intake remaining significant after controlling for potential confounding variables, is compatible with the reported low fruit and vegetable intakes by other researchers.[2,9–11]

To our knowledge, no published reports of the relationship between nutrients or dietary patterns and BP status have included analyses based on category of hypertension, ie, systolic, diastolic, or the combination. Analysis by these categories identified a new and potentially important distinction among type of hypertension and dietary components. In our analysis, dietary patterns differed significantly among BP categories. The nutritional pattern of lower intakes of all minerals including sodium and of macronutrients is unique to persons with isolated systolic hypertension. This group comprises approximately 60% of the hypertensive population in our samples. In contrast, persons with isolated diastolic hypertension demonstrate essentially the reverse pattern compared with individuals with isolated systolic hypertension.

The decision to analyze data by three BP categories warrants further comment. National treatment guidelines have encouraged treatment regimens tailored to treat isolated systolic hypertension as a condition that is different, at least in part, from that of elevated diastolic or mean arterial pressure. In our analysis, breaking this latter category into two groups (isolated diastolic hypertension and combined hypertension groups) may have revealed new insights. First, we are not aware of previous analyses of observational databases that have assessed whether isolated systolic hypertension is associated with a dietary pattern that differs from that associated with increased mean arterial pressure, as in isolated diastolic hypertension. Importantly, our findings from both NHANES III and IV suggest that dietary patterns do vary by BP category. Furthermore, they indicate that within the traditional category of elevated mean arterial pressure, dietary patterns may be distinguishable between patients with isolated systolic versus those with both diastolic and systolic BP elevations.

There are important interpretative limitations of this type of analysis. The methods of documenting recent dietary intake are subject to substantial bias, most commonly that of under-reporting intake of calories and selected nutrients, specifically fat. That issue has been documented for NHANES III.[15] Our data, however, provide several worthwhile insights as to these posited limitations in recall methods as they might apply to our findings. First, with the categorization of the BP status, BMI was significantly different among the groups. Those with isolated systolic hypertension were leaner, with significantly low mean BMI, and reported intake of fewer calories. The diastolic and mixed hypertension groups had higher mean BMI within a range generally regarded as overweight. This pattern of reported intakes was associated with excess BMI. Thus, the differing dietary patterns that we have observed do not appear to reflect under-reporting and are consistent with the notion that systolic hypertension is associated with a more normal BMI, older age, and lower caloric and nutrient intake.

These findings, as they relate to the putative association of dietary sodium intake to hypertension in the general population, provide a new perspective that may contribute to resolving the long-standing salt–BP issue.[16] Approximately 60% of the participants identified as hypertensive in both NHANES III and IV had isolated systolic hypertension. In both surveys, these individuals reported significantly lower sodium intakes. Approximately 20% of hypertensive participants in both NHANES III and IV had isolated diastolic hypertension. In NHANES IV these participants had higher sodium intakes than normotensive persons. The same trend was apparent, although not significant, in NHANES III.

These various percentages of BP categories are consistent with the typical distributions of salt sensitivity reported within the hypertensive population: ie, 60% to 70% are salt resistant and 30% to 40% salt sensitive. Based on our findings, the 60% of persons with newly diagnosed isolated systolic hypertension are unlikely to be salt sensitive, as their reported sodium intake is significantly less than that of subjects with normal BP. In contrast, diastolic hypertension with concurrent excess BMI may well reflect salt sensitivity, as sodium intake tends to be higher in these individuals than in normotensive persons and is significantly higher than in those with isolated systolic hypertension.

Although age, weight, ethnicity, and energy intake are known confounders of the relationship between BP and nutritional patterns, our analyses add another dimension to this relationship. Recognition that the association between specific nutrients or foods and BP status in adults is not uniform across all categories of hypertension has both research and policy implications. The decades-long debate regarding higher sodium intake and increased hypertension risk may be partially resolvable. Our data indicate that effects of sodium on BP are limited to those individuals with isolated diastolic hypertension with its accompanying higher BMI. Restricting sodium intake along with calories may prove specifically effective for these at-risk individuals. Randomized trials targeting this specific category of patients with an intervention that limits both calories and sodium intake are needed to test this hypothesis.

There is substantial collateral evidence that individuals at greatest cardiovascular risk, namely, older persons with systolic hypertension, will benefit from interventions that emphasize a dietary pattern that ensures adequate mineral consumption (calcium, potassium, and magnesium) regardless of sodium intake. Analyses of the randomized trials that have tested the BP effects of higher calcium or mineral intake have shown that the impact is greater and more consistent on systolic than on diastolic pressure.[8,17] These results are compatible with our findings. A prime example of a test of this hypothesis is the Dietary Approaches to Stop Hypertension (DASH) Trial.[2] In the initial report of that National Institutes of Health–funded study, a diet rich in minerals from dairy foods, fruits, and vegetables was found to be uniformly effective in lowering BP across all population groups, including hypertensive and normotensive individuals, and was independent of age, gender, and ethnicity as well as changes in weight or sodium intake.

In a subsequent report, the DASH diet combined with a normal sodium intake was particularly effective in older individuals with isolated systolic hypertension.[18] Most recently, Hajjar et al[19] confirmed the specific impact on age-related increases in systolic pressure of a mineral-rich diet in their analysis of NHANES III. A limitation of including patients with coronary heart disease and those on special diets in our sample is that their inclusion may have influenced both the dietary variables and the outcome variable, the mean of the BP readings.

Several meta-analyses of the trials of sodium restriction and BP have documented a heterogeneous effect on BP in the general population.[20–23] These analyses have typically indicated that the impact of restricting dietary sodium on BP is evident primarily in older persons with established hypertension. An intervention effect independent of sodium restriction has been identified by several of these analyses.[20–22] Collectively, these findings of heterogeneity and isolated effects in subpopulations are consistent with our analysis of NHANES III and IV as well as analyses of NHANES I and NHANES I follow-up[1,4,24] and support the emerging concept that the impact of diet on BP regulation is not uniform across the adult population. Additional analyses of available databases and appropriately structured randomized control trials will be critical to assessing the clinical importance of the findings derived from our concurrent analysis of NHANES III and IV.

In conclusion, our findings have several important implications for the prevention and management of hypertension and for future research initiatives. Clearly, the development of hypertension management guidelines in the future should be tailored to individual patients, as has generally been the approach with pharmacologic management, and not applied uniformly across all BP categories or groups at increased risk for hypertension. Furthermore, the emphasis of national nutrition policy on sodium restriction for hypertension is not consistent with these findings, identified in the federally funded NHANES databases, and warrants careful scientific evaluation.

Dietary interventions that improve overall diet quality by increasing the consumption of low-fat dairy foods, fruits, and vegetables, such as the DASH diet, have the greatest likelihood of improving BP status. The heterogeneity documented between BP status and nutrient intake in this analysis likely accounts for a substantial portion of the heterogeneous responses that have been observed in randomized controlled trials of diet modification for BP management. Future intervention trials should address these substantial differences in nutritional intakes based on hypertension category, particularly systolic hypertension, rather than presuming homogeneous effects of diet on regulation of arterial pressure.

References

1. McCarron DA, Morris CD, Henry HJ, Stanton JL: Blood pressure and nutrient intake in the United States. Science 1984;224:1392–1398.
2. Appel LJ, Moore TJ, Obarzanek E, Vollmer WM, Svetkey LP, Sacks FM, Bray GA, Vogt TM, Cutler JA, Windhauser MM, Lin PH, Karanja N, DASH Collaborative Research Group: A clinical trial of the effects of dietary patterns on blood pressure. N Engl J Med 1997;336:1117–1124.
3. Hamet P: The evaluation of the scientific evidence for a relationship between calcium and hypertension. J Nutr 1995;125:311S–400S.
4. Birkett NJ: Comments on a meta-analysis of the relation between dietary calcium intake and blood pressure. Am J Epidemiol 1998; 148:223–228.
5. Gruchow HW, Sobocinski KA, Barboriak JJ: Threshold effects of dietary calcium on blood pressure. J Hypertens 1986;4(Suppl 5): S355–S357.

6. Hamet P, Daignault-Gelinas M, Lambert J, Ledoux M, Whissell-Cambiotti L, Bellavance F, Mongeau E: Epidemiological evidence of an interaction between calcium and sodium intake impacting on blood pressure. A Montreal study. Am J Hypertens 1992;5:378–385.
7. Fodor JG, Abbott EC, Rusted IE: An epidemiologic study of hypertension in Newfoundland. Can Med Assoc J 1973;108:1365–1368.
8. Griffith L, Guyatt GH, Cook RJ, Bucher HC, Cook DJ: The influence of dietary and nondietary calcium supplementation on blood pressure: an updated metaanalysis of randomized clinical trials. Am J Hypertens 1999;12:84–92.
9. McCarron DA, Oparil S, Chait A, Haynes RB, Kris-Etherton P, Stern JS, Resnick LM, Clark S, Morris CD, Hatton DC, Metz JA, McMahon M, Holcomb S, Snyder GW, Pi-Sunyer FX: Nutritional management of cardiovascular risk factors: a randomized clinical trial. Arch Intern Med 1997;175:169–177.
10. Sacks FM, Svetkey LP, Vollmer WM, Appel LJ, Bray GA, Harsha DW, Obarzanek E, Conlin PR, Miller ER, Simons-Morton DG, Karanja N, Lin PH, Dasharathy G, DASH-Sodium Collaborative Research Group: Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. N Engl J Med 2001;344:3–10.
11. Resnick LM, Oparil S, Chait A, Haynes RB, Kris-Etherton P, Stern JS, Clark S, Holcomb S, Hatton DC, Metz JA, McMahon M, Pi-Sunyer FX, McCarron DA: Factors affecting blood pressure responses to diet: the Vanguard study. Am J Hypertens 2000;13: 956–965.
12. National Center for Health Statistics: Plan and operation of Third National Health and Nutrition Examination Survey, 1988–1994. Vital Health Stat 1994;1(32). Accessed at: *www.cdc.gov/nchs/data/nhanes/nhanes3/voc-acc.pdf*, May 2004.
13. Botman SL, Moore TF, Moriarity CL, Parsons VL: Design and estimation for the National Health Interview Survey, 1995–2004. Vital Health Stat 2000;2(130). Accessed at: *www.cdc.gov/nchs/products/pubs/pubd/series/sr02/130-121/sr2_130.htm*, May 2004.
14. Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure: The Sixth Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure. Arch Intern Med 1997;157:2413–2446.
15. Briefel RR, Sempos CT, McDowell MA, Chien S, Alaimo K: Dietary methods research in the Third National Health and Nutrition Examination Survey: underreporting of energy intake. Am J Clin Nutr 1997;65(Suppl):1203S–1209S.
16. Taubes G: The (political) science of salt. Science 1998;281:898–907.
17. Bucher HC, Cook RJ, Guyatt GH, Lang JD, Cook DJ, Hatala R, Hunt DL: Effects of dietary calcium supplementation on blood pressure: a meta-analysis of randomized controlled trials. J Am Med Assoc 1996;275:1016–1022.
18. Vollmer W, Sacks FM, Ard J, Appel LJ, Bray GA, Simons-Morton DG, Conlin PR, Svetkey LP, Erlinger TP, Moore TJ, Karanja N: Effects of dietary patterns and sodium intake on blood pressure: subgroup analysis of the DASH-Sodium trial. Ann Intern Med 2001;135:1019–1028.
19. Hajjar IM, Grim CE, Kotchen TA: Dietary calcium lowers the age-related rise in blood pressure in the United States: the NHANES III survey. J Clin Hypertens (Greenwich) 2003;5:122–126.
20. Midgley JP, Matthew AG, Greenwood CM, Logan AG: Effect of reduced dietary sodium on blood pressure: a meta-analysis of randomized controlled trials. J Am Med Assoc 1996;275:1590–1597.
21. Cutler JA, Follmann D, Allender PS: Randomized trials of sodium reduction: an overview. Am J Clin Nutr 1997;65:S643–S651.
22. Cutler JA, Follmann D, Elliott P, Suh I: An overview of randomized trials of sodium reduction and blood pressure. Hypertension 1991; 17:I27–I33.
23. Hooper L, Bartlett C, Davey SG, Ebrahim S: Systematic review of long term effects of advice to reduce dietary salt in adults. Br Med J 2002;325:628–636.
24. Alderman MH, Cohen H, Madhavan S: Dietary sodium intake and mortality: the National Health and Nutrition Examination Survey (NHANES I). Lancet 1998;351:781–785.