A Prospective Study of Nutritional Factors and Hypertension Among US Men

Alberto Ascherio, MD; Eric B. Rimm, ScD; Edward L. Giovannucci, MD; Graham A. Colditz, MD, DrPH; Bernard Rosner, PhD; Walter C. Willett, MD, DrPH; Frank Sacks, MD; and Meir J. Stampfer, MD, DrPH

Background. An effect of diet in determining blood pressure is suggested by epidemiological studies, but the role of specific nutrients is still unsettled.

Methods and Results. The relation of various nutritional factors with hypertension was examined prospectively among 30,681 predominantly white US male health professionals, 40–75 years old, without diagnosed hypertension. During 4 years of follow-up, 1,248 men reported a diagnosis of hypertension. Age, relative weight, and alcohol consumption were the strongest predictors for the development of hypertension. Dietary fiber, potassium, and magnesium were each significantly associated with lower risk of hypertension when considered individually and after adjustment for age, relative weight, alcohol consumption, and energy intake. When these nutrients were considered simultaneously, only dietary fiber had an independent inverse association with hypertension. For men with a fiber intake of <12 g/day, the relative risk of hypertension was 1.57 (95% confidence interval, 1.20–2.05) compared with an intake of >24 g/day. Calcium was significantly associated with lower risk of hypertension only in lean men. Dietary fiber, potassium, and magnesium were also inversely related to baseline systolic and diastolic blood pressure and to changes in blood pressure during the follow-up among men who did not develop hypertension. Calcium was inversely associated with baseline blood pressure but not with changes in blood pressure. No significant associations with hypertension were observed for sodium, total fat, or saturated, transunsaturated, and polyunsaturated fatty acids. Fruit fiber but not vegetable or cereal fiber was inversely associated with incidence of hypertension.

Conclusions. These results support hypotheses that an increased intake of fiber and magnesium may contribute to the prevention of hypertension. (Circulation 1992;86:1475–1484)

Key Words • blood pressure • diet • epidemiology • dietary fiber

A role for diet in determining blood pressure is suggested by international comparisons and studies of migrants and vegetarians. Alcohol intake and obesity increase blood pressure, but adjustment for these factors does not entirely explain observed differences among populations, suggesting that other aspects of diet may also influence blood pressure. However, the role of specific nutrients is still unsettled. In a recent international study, Interheart, large variations in salt intake had only a minor relation with blood pressure level, but reanalyses of observational and experimental data have suggested a stronger association of salt intake with blood pressure. Dietary potassium has been inversely related to blood pressure in some but not all cross-sectional studies, and supplementation trials have yielded conflicting results. Evidence that calcium, magnesium, and fiber reduce blood pressure is also inconclusive.

With few exceptions, epidemiological studies of diet and blood pressure have been cross-sectional rather than prospective. Also, most studies have used a 24-hour recall to measure diet, which, because of large within-person variation, is generally a poor reflection of an individual’s usual intake. Furthermore, some of these studies may have included hypertensive subjects who changed their diet because of the diagnosis.

In 1986, information on dietary intake over the preceding year and current usual blood pressure level was collected from a large cohort of US men. In the present analysis, we examined nutrient intakes in relation to blood pressure level at baseline and to changes in reported blood pressure and the diagnosis of hypertension during 4 years of follow-up.

Methods

Health Professionals Follow-up Study

The Health Professionals Follow-up Study is a prospective investigation of dietary etiologies of heart disease among men originally enrolled in the Health Professionals Follow-up Study (HPFS).

See p 1651
disease and cancer among 51,529 health professionals 40–75 years old. The study began in 1986 when cohort members completed a detailed food-frequency questionnaire and provided information about medical history, heart disease risk factors, and dietary changes during the past 10 years. Follow-up questionnaires were sent in 1987, 1988, and 1990. We excluded from analysis 1,533 men who did not satisfy the a priori criteria of daily caloric intake between 800 and 4,200 kilocalories and fewer than 70 blanks out of 131 total listed food items; 95% of the men included in the study had fewer than 15 blank food items. In addition, we excluded men who reported on the 1986 questionnaire a diagnosis of cancer (except nonmelanoma skin cancer) (n=2,002), myocardial infarction (n=2,226), angina (n=2,077), stroke (n=405), coronary artery surgery (n=1,801), hypertension (n=11,206), diabetes (n=1,608), renal failure (n=72), high blood cholesterol (n=6,362), or use of digoxin (n=1,040), nitrates (n=767), diuretics (n=4,847), β-blockers (n=4,912), calcium antagonists (n=1,146), or other antihypertensive drugs (n=1,663).

Men who reported high blood cholesterol were excluded because their baseline diet may not be representative of their long-term intakes. One or more of the above conditions were met by 19,315 participants, leaving 30,681 eligible men who were followed for hypertension incidence in the subsequent 4 years. The 1988 follow-up questionnaire was returned by 29,306 (95.5%) of that sample and the 1990 follow-up questionnaire by 27,698 (90.3%) as of the time of this analysis.

**Measurement of Dietary Intake and Other Exposure Variables**

The semiquantitative food-frequency questionnaire contained 131 items plus vitamin supplements. A description of the questionnaire and of the procedures for calculation of nutrient intake has been published previously. Nutrient intake was calculated for total energy, calcium, magnesium, potassium, dietary fiber, total fat, saturated fat, polyunsaturated fat, transunsaturated fatty acids, sodium, and alcohol. Calculation of sodium intake included amount of salt added during cooking of staple food (rice, pasta, potatoes, etc.), soup, vegetables, and meat and number of shakes of salt added to food at the table each day. Data on the reproducibility and validity of the food frequency questionnaire have been published elsewhere; compared with 2 weeks of dietary records provided by a subsample of 127 men and after adjustment for total caloric intake, correlations were calcium 0.53, magnesium 0.66, potassium 0.65, fiber 0.64, total fat 0.61, saturated fat 0.71, sodium 0.49, and polyunsaturated fat 0.29. The correlation between the food frequency questionnaire assessment of dietary polyunsaturated fatty acids and adipose polyunsaturated fatty acids (r=0.43) suggests that this nutrient was also relatively well measured. The unadjusted correlation coefficient for alcohol intake was 0.92. Correlation coefficients between reported and measured variables were 0.97 for weight and 0.69 for waist-to-hip ratio.

**Blood Pressure and Diagnosis of Hypertension**

In 1986, participants were asked to report their usual systolic and diastolic blood pressure within seven categories: <75, 75–84, 85–89, 90–94, 95–104, >105 mm Hg for diastolic and <120, 120–139, 140–149, 150–159, 160–169, >170 mm Hg for systolic. On subsequent biennial questionnaires, we inquired whether subjects had been diagnosed as having high blood pressure during the previous 2 years and, if so, the year of the diagnosis. In the 1990 questionnaire, we asked again for the current usual blood pressure (diastolic: <65, 65–74, 75–84, 85–89, 90–94, 95–104, >105 mm Hg; systolic: <105, 105–114, 115–124, 125–134, 135–144, 145–154, 155–164, 165–174, >175 mm Hg). To assess the validity of self-reported diagnosis of hypertension, we contacted a random sample of 100 participants reporting a diagnosis of hypertension on the 1988 questionnaire to obtain confirmation of the diagnosis and permission for review of their medical records. We obtained 95 responses; 77 men (81%) confirmed having had a physician diagnosis of hypertension. Records were obtained for 39 subjects. All had a diagnosis of high blood pressure recorded in the medical history or were receiving antihypertensive treatment. To investigate the likelihood of false-negative responses, blood pressure was measured in 1987 in a sample of 139 health professionals living in the greater Boston area. Among the 114 men without a previous self report of high blood pressure, only two had a blood pressure level ≥165/95.

Spearman correlation coefficients between self-reported blood pressure values in 1986 and blood pressure measured 4–13 months later were 0.50 for systolic and 0.32 for diastolic. The correlation for systolic blood pressure is similar to that for two measurements of blood pressure over this time period. To further assess the validity of self-reported blood pressure, we calculated the relative risk of subsequent incidence of stroke according to blood pressure levels reported on the baseline questionnaire. After adjustment for age and smoking, men who reported a baseline systolic blood pressure of 120–139 mm Hg had a relative risk of 2.2, and men who reported a baseline systolic blood pressure of 140–149 mm Hg had a relative risk of 3.7 compared with those with baseline systolic blood pressure <120 mm Hg. Men who reported a baseline diastolic blood pressure of 75–84 mm Hg had a relative risk of 2.0, and men who reported a baseline diastolic of 85–89 mm Hg had a relative risk of 4.2 compared with those with baseline diastolic <75 mm Hg.

**Data Analysis**

Exposure status was defined by responses to the 1986 questionnaire for all variables except height and waist and hip circumference, which were reported in 1987. Quetelet's index was calculated as weight (in kilograms) divided by the square of height (in meters). Nutrients were adjusted for total caloric intake as described elsewhere by regressing the nutrient intake on total energy intake. For each calorie-adjusted nutrient, we specified five levels of intake. Cut points were chosen a priori to obtain equally spaced categories, each containing a reasonable number of subjects.

Analyses of hypertension risk were based on 4-year cumulative incidence rates. Relative risks of hypertension with 95% confidence intervals were calculated by comparing each category of intake with the highest category. Linear trends in risks over successive categories were evaluated by entering into the models the median values of each category of exposure. Multiple
logistic regression analysis with categorical variables was used to control for confounding. Baseline systolic and diastolic blood pressures were not included as independent variables in primary analyses, because they can be considered as intermediate variables and their inclusion would cause an underestimation of the associations between nutrient intakes and risk of hypertension. Relative risks were also calculated within strata of age, Quetelet's index, and alcohol intake.

We examined the associations between nutrient intakes in 1986 and blood pressure reported in 1986 (baseline) and in 1990. We also assessed the associations of dietary factors with blood pressure change from 1986 to 1990 by using the 1990 pressure as the dependent variable and 1986 blood pressure as a covariate. Incident cases of hypertension were excluded. Because the elimination of men who developed hypertension may cause an underestimation of the effect of diet on blood pressure, however, we also repeated the analyses after assigning to men who developed hypertension a systolic blood pressure of 150 mm Hg and a diastolic blood pressure of 92.5 mm Hg. These values correspond approximately to the 95th percentile of blood pressure distribution in the cohort. Results of these repeated analyses were not materially different from those with cases of hypertension excluded and therefore, have not been included in this report. To control for confounding, models included age, Quetelet's index, and alcohol consumption; a quadratic term for age was included to account for the nonlinearity of the age-blood pressure association. Nutrients were added to the models as continuous variables to test for a linear trend between nutrient intakes and blood pressure. Analyses with indicator variables corresponding to categories of intake were also performed to assess the shape of the nutrient-blood pressure relations and to examine the associations of nutrient intakes with blood pressure within categories of other variables.

Finally, we examined the associations between intakes of several food groups and blood pressure. Foods were grouped as follows: sweets, meats, fish, cereals, fruit, vegetables, high-fat dairy, and low-fat dairy (see "Appendix"). The above combinations of foods were also used to define fiber intakes from specific food groups.

Results

During the four years of follow-up, 1,248 cases of hypertension were diagnosed. The 4-year cumulative incidence of hypertension rose from 2.8% for men 40-44 years old to 5.8% for men 70-75 years old (Figure 1). Baseline mean systolic blood pressure was 125.5 mm Hg at age 40-44 and 133.7 mm Hg at age 70-75, whereas diastolic blood pressure changed little: 79.3 mm Hg at age 40-44, 80.4 at age 60-64, and 79.7 at age 70-75. The Pearson correlation coefficient between baseline systolic and diastolic blood pressures was 0.48. Quetelet's index was strongly associated with an increasing risk of hypertension, and alcohol consumption was associated with risk of hypertension at intakes >30 g/day (Figure 2). Therefore, we controlled for age, Quetelet's index, and alcohol consumption in all further analyses; the model containing these variables will subsequently be referred to as the basic logistic model.
TABLE 1. Relative Risk of Hypertension by Level of Energy-Adjusted Daily Intake of Calcium, Magnesium, Potassium, and Fiber

<table>
<thead>
<tr>
<th></th>
<th>Calcium (g/day)</th>
<th>Magnesium (g/day)</th>
<th>Potassium (g/day)</th>
<th>Fiber (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;0.500</td>
<td>0.500–0.699</td>
<td>0.700–0.899</td>
<td>&lt;1.000</td>
</tr>
<tr>
<td>Cases (n)</td>
<td>85</td>
<td>297</td>
<td>333</td>
<td>195</td>
</tr>
<tr>
<td>Total (n)</td>
<td>1,673</td>
<td>7,504</td>
<td>8,576</td>
<td>5,038</td>
</tr>
<tr>
<td>Relative risk†</td>
<td>1.17</td>
<td>0.91</td>
<td>0.89</td>
<td>0.91</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>(0.91–1.50)</td>
<td>(0.77–1.07)</td>
<td>(0.76–1.04)</td>
<td>(0.76–1.09)</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>&lt;0.250</td>
<td>0.250–0.299</td>
<td>0.300–0.349</td>
<td>0.350–0.399</td>
</tr>
<tr>
<td>Cases (n)</td>
<td>78</td>
<td>201</td>
<td>292</td>
<td>299</td>
</tr>
<tr>
<td>Total (n)</td>
<td>1,507</td>
<td>4,522</td>
<td>7,317</td>
<td>7,238</td>
</tr>
<tr>
<td>Relative risk†</td>
<td>1.49</td>
<td>1.22</td>
<td>1.08</td>
<td>1.09</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>(1.15–1.92)</td>
<td>(1.02–1.46)</td>
<td>(0.92–1.26)</td>
<td>(0.93–1.28)</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>&lt;0.80–1.56</td>
<td>0.85–1.33</td>
<td>0.81–1.18</td>
<td>0.88–1.22</td>
</tr>
<tr>
<td>Potassium (g/day)</td>
<td>&lt;2.40</td>
<td>2.40–2.79</td>
<td>2.80–3.19</td>
<td>3.20–3.59</td>
</tr>
<tr>
<td>Cases (n)</td>
<td>79</td>
<td>170</td>
<td>270</td>
<td>322</td>
</tr>
<tr>
<td>Total (n)</td>
<td>1,466</td>
<td>3,857</td>
<td>7,002</td>
<td>7,520</td>
</tr>
<tr>
<td>Relative risk†</td>
<td>1.54</td>
<td>1.26</td>
<td>1.05</td>
<td>1.17</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>(1.19–1.96)</td>
<td>(1.04–1.51)</td>
<td>(0.89–1.23)</td>
<td>(1.0–1.36)</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>&lt;0.87–1.66</td>
<td>0.88–1.39</td>
<td>0.82–1.18</td>
<td>0.96–1.33</td>
</tr>
<tr>
<td>Fiber (g/day)</td>
<td>&lt;12.0</td>
<td>12.0–15.9</td>
<td>16.0–19.9</td>
<td>20.0–23.9</td>
</tr>
<tr>
<td>Cases (n)</td>
<td>75</td>
<td>227</td>
<td>284</td>
<td>280</td>
</tr>
<tr>
<td>Total (n)</td>
<td>1,288</td>
<td>4,946</td>
<td>7,328</td>
<td>6,818</td>
</tr>
<tr>
<td>Relative risk†</td>
<td>1.57</td>
<td>1.38</td>
<td>1.07</td>
<td>1.14</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>(1.20–2.05)</td>
<td>(1.16–1.64)</td>
<td>(0.91–1.25)</td>
<td>(0.97–1.33)</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>&lt;1.09–1.96</td>
<td>1.06–1.59</td>
<td>0.86–1.23</td>
<td>0.94–1.31</td>
</tr>
<tr>
<td>Fiber (g/day)</td>
<td>&lt;12.0</td>
<td>12.0–15.9</td>
<td>16.0–19.9</td>
<td>20.0–23.9</td>
</tr>
<tr>
<td>Cases (n)</td>
<td>75</td>
<td>227</td>
<td>284</td>
<td>280</td>
</tr>
<tr>
<td>Total (n)</td>
<td>1,288</td>
<td>4,946</td>
<td>7,328</td>
<td>6,818</td>
</tr>
<tr>
<td>Relative risk†</td>
<td>1.57</td>
<td>1.38</td>
<td>1.07</td>
<td>1.14</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>(1.20–2.05)</td>
<td>(1.16–1.64)</td>
<td>(0.91–1.25)</td>
<td>(0.97–1.33)</td>
</tr>
</tbody>
</table>

*χ and p value for trend.
†Model includes age, Quetelet's index, and alcohol consumption.
‡Model includes age, Quetelet's index, alcohol consumption, and intakes of magnesium, potassium, and fiber.

hypertension, but adding these variables to the basic logistic model did not alter the observed associations between dietary factors and hypertension. Exclusion of Quetelet's index and alcohol intake from the model produced only a slight change in the associations between nutrient intakes and hypertension; age-adjusted (and multivariate-adjusted) relative risks comparing the bottom with the top category of intake were 1.24 (1.17) for calcium, 1.56 (1.49) for magnesium, 1.61 (1.54) for potassium, and 1.82 (1.57) for fiber. Significant inverse associations of magnesium, potassium, and fiber with risk of hypertension were found also in analyses restricted to the 17,640 men who reported having had a physical examination between 1988 and 1990 (data not shown).

As expected, baseline systolic and diastolic blood pressures were strongly associated with risk of subsequent diagnosis of hypertension. Among nutrient intakes, only fiber remained significantly associated with risk of hypertension when baseline diastolic and systolic blood pressures were added to the basic model (relative risk, 1.36; 95% confidence interval, 1.04–1.78).

We further explored the associations of magnesium, potassium, and fiber with risk of hypertension by adding them to the basic logistic model two at a time. When fiber was in the model, the associations of potassium and magnesium with hypertension were weakened (relative risk for lowest versus highest category of intake, 1.30 and 1.22; tests for trend, p=0.20 and p=0.17, respectively), whereas the association of fiber with hypertension was only slightly reduced (relative risk, 1.49 with either potassium or magnesium in the model; test for trend, p=0.006). When included simultaneously, potassium and magnesium both had weak and nonsignificant associations with hypertension (relative risks, 1.32 and 1.28; tests for trend, p=0.08 and p=0.14, respectively). When magnesium, potassium, and fiber were added simultaneously to the basic logistic model, only dietary fiber remained independently associated with risk of hypertension (Table 1).

The inverse associations between nutrient intakes and hypertension were stronger in men <50 years old. Calcium was inversely associated with hypertension in men with low relative weight (Table 2). The inverse association between calcium intake and hypertension in men with low relative body weight remained after adjustment simultaneously for magnesium, potassium, and fiber intake (relative risk for lowest versus highest category of intake, 3.60; 95% confidence interval, 1.75–7.38).

In general, the associations of nutrients with systolic or diastolic blood pressures at baseline were similar to the associations with the diagnosis of hypertension. Sodium intake, when added as a continuous variable to multiple linear regression models, was not significantly associated with systolic blood pressure (regression coefficient, b = −0.08 mm Hg/g, p = 0.11) and was inversely associated with diastolic blood pressure (b = −0.09
Categorical analyses of baseline nutrient intake and blood pressure (Table 5) confirmed the analyses using blood pressure as a continuous variable. In the lowest versus the highest categories of intake, blood pressures were 1 mm Hg higher for calcium and 1.5–2.0 mm Hg higher for magnesium, potassium, and fiber (Table 5). For calcium, most of the increase in blood pressure occurred at intakes <0.5 g/day. When the four nutrients were included at the same time, only magnesium and fiber were significantly associated with blood pressure (Table 6).

When fibers from different foods were added one at a time to the basic logistic model, only fiber from fruit had a significant inverse association with risk of hypertension (relative risk, 1.23; 95% confidence interval, 1.04–1.54, comparing bottom versus top quintile of intake). This association remained after adjustment for fiber from other sources (relative risk, 1.23; 95% confidence interval, 1.01–1.52). Fiber from vegetables, cereals, and fruits had similar significant inverse associations with baseline diastolic blood pressure, but only fruit fiber and, less strongly, vegetable fiber were inversely associated with systolic blood pressure.

In analyses of food groups, only fruit had a significant relation with risk of hypertension (relative risk for lowest versus highest quintile of intake, 1.20; 95% confidence interval, 1.01–1.45) and with baseline sys-
Table 3. Multiple Regression Coefficients in Models With Self-Reported Systolic Blood Pressure as the Dependent Variable

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>1986 Systolic (mm Hg) (n=26,156)</th>
<th>1990 Systolic (mm Hg) (n=20,523)</th>
<th>Systolic change (mm Hg) (n=18,911)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>SE</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Basic model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>121.1</td>
<td>1.96</td>
<td>112.8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>-0.545*</td>
<td>0.073</td>
<td>-0.520*</td>
</tr>
<tr>
<td>Age^2 (years^2)</td>
<td>0.007*</td>
<td>0.0007</td>
<td>0.0078*</td>
</tr>
<tr>
<td>Quetelet's index (kg/m^2)</td>
<td>0.574*</td>
<td>0.019</td>
<td>0.676*</td>
</tr>
<tr>
<td>Ethanol (g/day)</td>
<td>0.045*</td>
<td>0.004</td>
<td>0.056*</td>
</tr>
<tr>
<td>1986 Systolic (mm Hg)</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1986 Diastolic (mm Hg)</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Added to basic model one at a time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (g/day)</td>
<td>-0.635*</td>
<td>0.139</td>
<td>-0.289</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>-6.66*</td>
<td>0.64</td>
<td>-5.04*</td>
</tr>
<tr>
<td>Potassium (g/day)</td>
<td>-0.744*</td>
<td>0.084</td>
<td>-0.606*</td>
</tr>
<tr>
<td>Dietary fiber (g/day)</td>
<td>-0.076*</td>
<td>0.008</td>
<td>-0.076*</td>
</tr>
<tr>
<td>Added to basic model simultaneously</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (g/day)</td>
<td>-0.209</td>
<td>0.158</td>
<td>-0.010</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>-3.37‡</td>
<td>0.97</td>
<td>-1.26</td>
</tr>
<tr>
<td>Potassium (g/day)</td>
<td>-0.116</td>
<td>0.122</td>
<td>-0.113</td>
</tr>
<tr>
<td>Dietary fiber (g/day)</td>
<td>-0.044*</td>
<td>0.010</td>
<td>-0.061*</td>
</tr>
</tbody>
</table>

Change modeled by including 1986 systolic and diastolic blood pressures in a model with 1990 systolic as dependent variable. Number of subjects included in the model changes because of exclusion of men with unknown blood pressure values.

*p<0.0001; †p<0.01; ‡p<0.001.

Systolic blood pressure. None of the food groups was significantly associated with diastolic blood pressure.

When added to the basic models one at a time, individual fruit items had weak or no association with blood pressure. Intakes of strawberries, blueberries, and peaches were each inversely associated with baseline diastolic blood pressure, and strawberry intake was inversely associated with baseline diastolic blood pressure.

Discussion
Within this large cohort of men, we observed inverse associations for dietary fiber, potassium, and magne-

Table 4. Multiple Regression Coefficients in Models With Self-Reported Diastolic Blood Pressure as the Dependent Variable

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>1986 Diastolic (mm Hg) (n=26,156)</th>
<th>1990 Diastolic (mm Hg) (n=21,189)</th>
<th>Diastolic change (mm Hg) (n=18,676)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>SE</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Basic model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>61.04</td>
<td>1.35</td>
<td>52.4</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.295*</td>
<td>0.051</td>
<td>0.570*</td>
</tr>
<tr>
<td>Age^2 (years^2)</td>
<td>-0.002*</td>
<td>0.0005</td>
<td>-0.052*</td>
</tr>
<tr>
<td>Quetelet's index (kg/m^2)</td>
<td>0.396*</td>
<td>0.013</td>
<td>0.447*</td>
</tr>
<tr>
<td>Ethanol (g/day)</td>
<td>0.025*</td>
<td>0.0026</td>
<td>0.039*</td>
</tr>
<tr>
<td>Systolic pressure (mm Hg)‡</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Diastolic pressure (mm Hg)‡</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Added to basic model one at a time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (g/day)</td>
<td>-0.574*</td>
<td>0.095</td>
<td>-0.373‡</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>-5.63*</td>
<td>0.44</td>
<td>-3.94*</td>
</tr>
<tr>
<td>Potassium (g/day)</td>
<td>-0.652*</td>
<td>0.058</td>
<td>-0.498*</td>
</tr>
<tr>
<td>Dietary fiber (g/day)</td>
<td>-0.058*</td>
<td>0.005</td>
<td>-0.049*</td>
</tr>
<tr>
<td>Added to basic model simultaneously</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (g/day)</td>
<td>-0.163</td>
<td>0.101</td>
<td>-0.104</td>
</tr>
<tr>
<td>Magnesium (g/day)</td>
<td>-3.09*</td>
<td>0.68</td>
<td>-1.36</td>
</tr>
<tr>
<td>Potassium (g/day)</td>
<td>-0.174†</td>
<td>0.084</td>
<td>-0.164</td>
</tr>
<tr>
<td>Dietary fiber (g/day)</td>
<td>-0.026€</td>
<td>0.007</td>
<td>-0.030€</td>
</tr>
</tbody>
</table>

Change modeled by including 1986 systolic and diastolic blood pressure in a model with 1990 diastolic as dependent variable. Number of subjects included in the model changes because of exclusion of men with unknown blood pressure values.

*p<0.0001, †p<0.05, ‡p<0.001.
Calcium (g/day) & <0.500 & 0.500–0.699 & 0.700–0.899 & 0.900–1.099 & ≥1,100 (Reference) \\
Systolic (mm Hg) & 1.03 & 0.41 & 0.44 & 0.00 & 0 \\
95% Confidence interval & (0.49, 1.57) & (0.09, 0.72) & (0.14, 0.75) & (–0.36, 0.36) & ... \\
Diastolic (mm Hg) & 1.01 & 0.49 & 0.38 & 0.00 & 0 \\
95% Confidence interval & (0.64, 1.38) & (0.27, 0.71) & (0.17, 0.59) & (–0.24, 0.24) & ... \\
Magnesium (g/day) & <0.250 & 0.250–0.299 & 0.300–0.349 & 0.350–0.399 & ≥0.400 (Reference) \\
Systolic (mm Hg) & 2.08 & 1.52 & 0.95 & 0.50 & 0 \\
95% Confidence interval & (1.52, 2.64) & (1.16, 1.87) & (0.65, 1.25) & (0.20, 0.80) & ... \\
Diastolic (mm Hg) & 1.67 & 1.31 & 0.95 & 0.50 & 0 \\
95% Confidence interval & (1.29, 2.05) & (1.06, 1.55) & (0.74, 1.16) & (0.29, 0.70) & ... \\
Potassium (g/day) & <2.40 & 2.40–2.79 & 2.80–3.19 & 3.20–3.59 & ≥3.60 (Reference) \\
Systolic (mm Hg) & 1.78 & 1.07 & 0.81 & 0.45 & 0 \\
95% Confidence interval & (1.21, 2.33) & (0.69, 1.44) & (0.50, 1.11) & (0.16, 0.74) & ... \\
Diastolic (mm Hg) & 1.58 & 0.93 & 0.79 & 0.42 & 0 \\
95% Confidence interval & (1.19, 1.97) & (0.67, 1.18) & (0.58, 1.00) & (0.22, 0.62) & ... \\
Fiber (g/day) & <12.0 & 12.0–15.9 & 16.0–19.9 & 20.0–23.9 & ≥24.0 (Reference) \\
Systolic (mm Hg) & 1.91 & 1.30 & 1.03 & 0.77 & 0 \\
95% Confidence interval & (1.31, 2.51) & (0.94, 1.66) & (0.73, 1.33) & (0.47, 1.08) & ... \\
Diastolic (mm Hg) & 1.59 & 1.02 & 0.85 & 0.57 & 0 \\
95% Confidence interval & (1.19, 2.00) & (0.77, 1.27) & (0.64, 1.06) & (0.37, 0.78) & ... \\

*Model includes age, age², Quetelet’s index, alcohol consumption, and intake of saturated fat, polyunsaturated fat, and sodium.

TABLE 6. Baseline (1986) Systolic and Diastolic Blood Pressure Differences Between Different Categories of Calcium, Magnesium, Potassium, and Fiber Intakes Using the Highest Category as the Reference

Calcium (g/day) & <0.500 & 0.500–0.699 & 0.700–0.899 & 0.900–1.099 & ≥1,100 (Reference) \\
Systolic (mm Hg) & 0.23 & –0.01 & 0.25 & –0.07 & 0 \\
95% Confidence interval & (–0.32, 0.78) & (–0.36, 0.34) & (–0.06, 0.56) & (–0.42, 0.28) & ... \\
Diastolic (mm Hg) & 0.34 & 0.12 & 0.19 & –0.09 & 0 \\
95% Confidence interval & (–0.05, 0.73) & (–0.12, 0.36) & (–0.03, 0.41) & (–0.34, 0.16) & ... \\
Magnesium (g/day) & <0.250 & 0.250–0.299 & 0.300–0.349 & 0.350–0.399 & ≥0.400 (Reference) \\
Systolic (mm Hg) & 1.38 & 1.04 & 0.59 & 0.29 & 0 \\
95% Confidence interval & (0.65, 2.11) & (0.57, 1.51) & (0.22, 0.96) & (–0.02, 0.60) & ... \\
Diastolic (mm Hg) & 0.96 & 0.86 & 0.63 & 0.33 & 0 \\
95% Confidence interval & (0.47, 1.45) & (0.55, 1.17) & (0.38, 0.88) & (0.11, 0.55) & ... \\
Potassium (g/day) & <2.40 & 2.40–2.79 & 2.80–3.19 & 3.20–3.59 & ≥3.60 (Reference) \\
Systolic (mm Hg) & 0.29 & –0.01 & 0.08 & 0.06 & 0 \\
95% Confidence interval & (–0.42, 1.00) & (–0.48, 0.46) & (–0.27, 0.43) & (–0.25, 0.37) & ... \\
Diastolic (mm Hg) & 0.43 & 0.05 & 0.17 & 0.07 & 0 \\
95% Confidence interval & (–0.06, 0.92) & (–0.26, 0.36) & (–0.08, 0.42) & (–0.15, 0.29) & ... \\
Fiber (g/day) & <12.0 & 12.0–15.9 & 16.0–19.9 & 20.0–23.9 & ≥24.0 (Reference) \\
Systolic (mm Hg) & 1.10 & 0.66 & 0.58 & 0.51 & 0 \\
95% Confidence interval & (0.43, 1.77) & (0.23, 1.09) & (0.23, 0.93) & (0.20, 0.82) & ... \\
Diastolic (mm Hg) & 0.85 & 0.41 & 0.40 & 0.30 & 0 \\
95% Confidence interval & (0.40, 1.30) & (0.12, 0.70) & (0.16, 0.64) & (0.08, 0.52) & ... \\

*Model includes age, age², Quetelet’s index, alcohol consumption, and intake of saturated fat, polyunsaturated fat, and sodium.
pressure would increase the standard error of the estimated regression coefficients for dietary intakes, age, Quetelet’s index, and alcohol consumption but would not bias their point estimates. In assessing the associations of diet with changes in blood pressure between 1986 and 1990, however, regression to the mean of the reported blood pressure values may weaken the observed associations of dietary and other variables with blood pressure changes. The validity of blood pressure values and diagnosis of hypertension in this study is supported by the results of a subsample study that confirm established associations of age and relative weight with incidence of hypertension and blood pressure levels and in particular by the strong association of blood pressure levels with risk of future cardiovascular disease. Furthermore, detection bias is unlikely to explain the observed associations, because these findings were not weakened by restriction of the analyses to men who reported having had a physical examination between 1988 and 1990. Because diet was measured before diagnosis, it is reasonable to assume that associations were relatively unbiased with respect to hypertension status; in the event that knowledge of borderline hypertension might have caused men to change their diets, the direction of any change would have been more likely to obscure relations with nutrients than to create them. For these reasons, the strength of the observed associations probably represents an underestimation of the true effects of diet. Our results do not exclude a possible positive association between sodium intake and risk of hypertension, however, because some men may have reduced their sodium intake in response to high blood pressure values.

An inverse association between dietary fiber intake and blood pressure has been observed previously. In a prospective study of over 58,000 nurses, using a similar validated measurement of nutrient intakes, the relative risk for developing hypertension in women was 0.76 for fiber intake >25 g/day compared with intake <10 g/day ($p=0.002$). The association was weakened after adjustment for intakes of calcium, magnesium, and potassium but still compatible with a protective effect (95% confidence interval, 0.71–1.05). Other cross-sectional retrospective studies have reported inverse associations of blood pressure with dietary fiber. Also, a blood pressure–reducing effect of an increased fiber intake has been observed in a nonrandomized intervention study.

A significant treatment-related reduction in blood pressure (−11 mm Hg systolic, $p=0.02$, and −6 mm Hg diastolic, $p=0.04$) was obtained in a randomized double-blind study comparing tablets providing 7 g/day of fiber from grain, citrus fruit, and vegetables with a placebo. Other randomized trials, however, did not show an effect of fiber on blood pressure in healthy normotensive volunteers, hypercholesterolemic subjects, or overweight individuals who received fiber tablets as a supplement to a weight-reducing diet. Specific fiber components used as supplements in these trials included soy cotyledon fiber, wheat, rice, or oat fiber, guar gum, and instant oats; baseline fiber intake ranged from 13 to 19.8 g/day among the six trials in which it was reported.

Overall results from dietary trials do not support a blood pressure–reducing effect of short-term dietary fiber suplementation. The combined evidence from observational and experimental studies could be explained if fiber intake affects blood pressure either only after prolonged administration or only in subjects with a lower baseline intake than that of subjects recruited in clinical trials. Alternatively, some other dietary component highly correlated with fiber or possibly a specific fiber type may have a blood pressure–lowering action. The finding of an inverse association of intake of fruit and fruit fiber but not of cereal and vegetable intakes with blood pressure in this and in a previous study suggests that some other fruit component may lower blood pressure.

The lack of an independent association of calcium intake with blood pressure in this large cohort of men is consistent with the results of most randomized trials. It appears from our results, however, that leanness may be a predictor of response to calcium supplementation in subjects who have a low baseline calcium intake. A dependency of the association between calcium intake and blood pressure on relative weight was observed also among women and, if confirmed, might explain— together with the nonlinearity of the association of calcium with blood pressure—the conflicting results obtained in previous observational and experimental studies.

The highly significant inverse association of magnesium with both systolic and diastolic pressures in cross-sectional analysis was independent of fiber intake. A low magnesium intake was found to be the dietary factor more strongly associated with high blood pressure in the analyses of data from the Honolulu Heart Study and from the Nurses’ Health Study. However, magnesium supplementation trials have yielded conflicting results. These studies, because of small size or short duration, were unlikely to detect a short-term modest effect or a long-term inhibition of magnesium intake on the rise of blood pressure. Also, it has been suggested that there are subgroups of responders that may benefit from magnesium supplementation.

The results of our study strengthen the evidence that diet has an independent effect on blood pressure. Such effect is small compared with that of obesity but not irrelevant. In our study population, assuming that the relative risks estimated represent causal associations, a reduction of Quetelet’s index to <23 in all men would prevent 46.7% of cases of hypertension, reduction of alcohol intake to less than 30 g/day (2 drinks per day) would prevent 3.8% of cases, and an increase of dietary fiber intake to 24 g/day or more would prevent 11.1% of cases. A greater effect of fiber would be estimated by correcting for error in measuring fiber intake. On the other hand, if the association between fiber intake and hypertension were to be explained by some not yet identified dietary component, such component should necessarily have a stronger effect on blood pressure than fiber and therefore be a potential candidate for intervention. Finally, despite their relatively small effect, dietary changes may be the most effective blood pressure–lowering intervention for those individuals who are lean and are not heavy drinkers.

Acknowledgments

We thank the participants of the Health Professionals Follow-up Study for their continued cooperation and Mary.
Appendix

Foods were grouped as follows: sweets (chocolate, candies, cookies, brownies, donuts, cakes, pies, sweet rolls, and jam); meats (processed meats, bacon, hot dogs, hamburgers, beef, pork, lamb, and chicken); fish (tuna, dark fish, other fish, and shrimp); cereals (cold cereal, cooked oats, cooked cereals, white bread, dark bread, English muffins, muffins, brown rice, white rice, pasta, other grains, pancakes, potatoes, and crackers); fruit (raisins, grapes, avocados, bananas, cantaloupe, watermelons, apples, apple juice, oranges, orange juice, grapefruits, grapefruit juice, other fruit juice, strawberries, blueberries, and peaches); vegetables (string beans, broccoli, sauerkraut, coleslaw, cabbage, cauliflower, brussels sprouts, carrots, corn, peas, beans, lentils, alfalfa sprouts, celery, mushrooms, yellow squash, yams, spinach, kale, iceberg lettuce, romaine lettuce, green pepper, garlic, tomatoes, tomato juice, tomato sauce, red chili sauce, tofu, and soybeans); high-fat dairy (milk, cream, ice cream, cream cheese, other cheese, butter, sour cream); low-fat dairy (skim milk, sherbet, cottage cheese, yogurt).

References

55. TOHP Collaborative Research Group: The effects of nonpharmacologic interventions on blood pressure of persons with high normal levels: Results of the trials of hypertension prevention, phase 1. *JAMA* 1992;267:1213–1220
A prospective study of nutritional factors and hypertension among US men.
A Ascherio, E B Rimm, E L Giovannucci, G A Colditz, B Rosner, W C Willett, F Sacks and M J Stampfer

Circulation. 1992;86:1475-1484
doi: 10.1161/01.CIR.86.5.1475

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1992 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/86/5/1475

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/