Relationship of Dietary Sodium, Potassium, Calcium, and Magnesium with Blood Pressure
Belgian Interuniversity Research on Nutrition and Health

Hugo Kesteloot and Jozef V. Joossens

SUMMARY From 1979 through 1984, a randomized epidemiological survey in Belgium assessed the dietary intake of sodium, potassium, calcium, and magnesium using 24-hour food records checked by trained dietitians. Dietary cation intake levels were correlated with blood pressure both in the total group (4167 men and 3891 women) and in the group not taking antihypertensive medication (3814 men and 3329 women). Serum sodium, potassium, calcium, and phosphorus were also measured. Multiple regression analysis adjusting for age, body mass index, heart rate, alcohol intake, and total caloric intake revealed a significant positive correlation between sodium intake and blood pressure in the group not treated for hypertension except for diastolic blood pressure in women. A significant negative correlation was found between dietary calcium intake and diastolic blood pressure in men and between dietary magnesium intake and systolic blood pressure in women. No independent effect of dietary potassium intake on blood pressure could be established. Significant but weak correlations were found between the dietary intake of sodium, potassium and calcium and their serum values. The study confirms the hypothesis that at the population level dietary cations are related to the regulation of blood pressure. (Hypertension 12: 594–599, 1988)

KEY WORDS • blood pressure • dietary sodium • dietary potassium • dietary calcium • dietary magnesium • serum sodium • serum calcium • serum potassium • serum phosphorus

Hypertension and its consequences, especially stroke, remain a major health problem in nearly all populations throughout the world. Differences in diet and, more specifically, in the intake of salt have been held responsible for differences in blood pressure and cerebrovascular mortality between populations. At the population level, the relationship of dietary cations and their interactions with blood pressure remains complex. This complexity is further enhanced by a scarcity of data. During the Belgian Interuniversity Research on Nutrition and Health (BIRNH) Study, blood pressure was measured and a dietary survey was performed in a randomized population sample in Belgium. This enabled us to study the relationship between dietary cations and blood pressure in a large population group.

Subjects and Methods
A nutritional survey of men and women aged between 25 and 74 years (mean age, 48 ± 13 years) was carried out from 1979 through 1984 in a randomized Belgian population sample. The goals and details of the study have been published previously1 and will only be summarized here. In each of the 42 Belgian counties, a randomized population sample was drawn from the voting lists and the selected subjects were invited to participate in a health study concerning the relationship of diet with cardiovascular risk factors and regional mortality. Since the participation rate was low (between 31 and 46% of the selected subjects), an additional 10% random sample of the nonresponders was taken and was shown to be similar to the original group regarding dietary habits standardized for kilocalories. During the survey blood pressure was measured twice with subjects in the sitting position, and the mean of the two measurements was used for calculation. The fifth phase of the Korotkoff sounds was recorded as diastolic pressure. Blood pressure was measured by means of a Hawksley random-zero sphygmomanometer (Lancing, Sussex, UK) after the participant had been interviewed by the dietitian about the dietary questionnaire. In between the two blood
pressure determinations heart rate was measured by means of a chronometer over a period of 30 seconds. Weight was measured after subjects had removed heavy outer garments and shoes.

From the 24-hour food record, obtained by questionnaire and checked during an interview between a trained dietician and the participant, the 24-hour consumption of sodium, potassium, calcium, and magnesium was calculated. For potassium, calcium, and magnesium, this amount corresponds closely to the daily intake of these cations. However, the calculated amount does not correspond to the actual intake for sodium, since discretionary sodium added to the diet is not considered by this method. The sodium, potassium, calcium, and magnesium content of the various food items was obtained from the food composition tables of Paul and Southgate\(^2\) and from the Dutch food tables,\(^3\) which were used for the calculation of the potassium content. The food intake of only 1 day—the 24 hours preceding the day of the interview (including Sundays)—was recorded.

Serum sodium and potassium were measured by flame photometry, serum calcium by atomic absorption, and serum phosphorus as phosphate by a modified method using ammonium molybdate.\(^4\) The serum sample was obtained in nonfasting subjects after the blood pressure measurement.

The data were submitted to multiple regression analysis using the stepdown method until all remaining factors were significant at a \(p\) level below 0.05. Systolic (SBP) and diastolic blood pressure (DBP) were the dependent variables, and age, body mass index, heart rate, dietary sodium, potassium, calcium, magnesium, alcohol consumption, and total caloric intake were used as independent variables. The analysis was performed on the total group and on the group not taking antihypertensive medication (untreated group), in men and women separately. Standardized partial regression coefficients were calculated by multiplying the partial regression coefficient with the SD of its independent variable and dividing it by the SD of the dependent variable. Body mass index was used as an index of obesity and obtained by dividing weight (in kilograms) by height (expressed in square meters).

### Results

The anthropometric, blood pressure, and dietary data for men and women are given in Table 1, and the cation consumption data are given in Table 2. The male/female ratios for dietary sodium, potassium, and calcium intake for the total group were 1.46, 1.22, and 1.12, respectively, as compared with 1.36 for total caloric intake. It was nearly identical for the group not taking antihypertensive medication. The relationships between dietary cation values and values for serum cations, total protein, cation ratios, and phosphorus are given in Table 3 for the total group and in Table 4 for the group not being treated for hypertension. Some highly significant correlations were found between the dietary and serum variables, particularly with serum phosphorus and with the serum sodium/potassium and calcium/magnesium ratios.

The relationship of the dietary cations, analyzed by means of multiple regression analysis with the inclusion of age, body mass index, heart rate, and dietary sodium, potassium, calcium, magnesium, alcohol consumption, and total caloric intake used as independent variables. The analysis was performed on the total group and on the group not taking antihypertensive medication (untreated group), in men and women separately. Standardized partial regression coefficients were calculated by multiplying the partial regression coefficient with the SD of its independent variable and dividing it by the SD of the dependent variable. Body mass index was used as an index of obesity and obtained by dividing weight (in kilograms) by height (expressed in square meters).

### Table 1. Anthropometric and Dietary Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total group</th>
<th>Untreated group</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Men (n=4167)</td>
<td>Women (n=3891)</td>
</tr>
<tr>
<td></td>
<td>Men (n=3814)</td>
<td>Women (n=3329)</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>49.2±13.7</td>
<td>48.4±13.7</td>
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<td></td>
<td>46.5±12.9</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>25.9±3.5</td>
<td>25.8±3.4</td>
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<td>25.4±4.4</td>
<td>25.4±17.3</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>72.4±11.3</td>
<td>72.6±11.1</td>
</tr>
<tr>
<td></td>
<td>75.7±11.1</td>
<td>76.2±11.0</td>
</tr>
<tr>
<td>Dietary alcohol (g/day)</td>
<td>22.3±34.2</td>
<td>22.9±34.8</td>
</tr>
<tr>
<td></td>
<td>6.4±12.9</td>
<td>6.9±13.4</td>
</tr>
<tr>
<td>Food intake (kcal/day)</td>
<td>2881±972</td>
<td>2923±967</td>
</tr>
<tr>
<td></td>
<td>2117±669</td>
<td>2156±673</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>136.2±18.1</td>
<td>134.8±17.2</td>
</tr>
<tr>
<td></td>
<td>131.7±21.0</td>
<td>128.3±18.8</td>
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<tr>
<td>DBP (mm Hg)</td>
<td>82.2±12.1</td>
<td>81.5±11.8</td>
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<tr>
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<td>79.8±12.4</td>
<td>78.4±11.7</td>
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</tbody>
</table>

Values are means ± SD. The untreated group is the group not taking antihypertensive medication.

### Table 2. Dietary Cation Intake

<table>
<thead>
<tr>
<th>Group</th>
<th>Na (mg/day)</th>
<th>K (mg/day)</th>
<th>Ca (mg/day)</th>
<th>Mg (mg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men Total</td>
<td>2496±1318</td>
<td>3859±1262</td>
<td>841±528</td>
<td>397±145</td>
</tr>
<tr>
<td>Untreated</td>
<td>2399±1313</td>
<td>3896±1260</td>
<td>852±537</td>
<td>401±145</td>
</tr>
<tr>
<td>Women Total</td>
<td>1710±826</td>
<td>3155±930</td>
<td>748±413</td>
<td>306±100</td>
</tr>
<tr>
<td>Untreated</td>
<td>1741±821</td>
<td>3200±939</td>
<td>759±419</td>
<td>312±100</td>
</tr>
</tbody>
</table>

Values are means ± SD. Dietary values were obtained from 24-hour food-record data (see Subjects and Methods). The untreated group is the group not taking antihypertensive medication.
alcohol intake, and total caloric intake, with blood pressure is given in Table 5 for the total group and in Table 6 for the group not taking antihypertensive medication. As can be seen from the standardized partial regression coefficients, the most important variables explaining blood pressure variations are age, body mass index, and heart rate. In the total group, significant positive independent relationships existed between dietary sodium intake and DBP in men and women, between alcohol intake and SBP and DBP only in men, and between total caloric intake and SBP only in women. Significant negative associations existed between dietary calcium intake and DBP in men, between dietary magnesium intake and SBP in women, and between total caloric intake and DBP in women. Significant relationships were found in the group not being treated for hypertension, except that in men a positive significant relation was also established between dietary calcium intake and DBP. Whenever the correlation was significant, dietary sodium and alcohol intake were associated positively with blood pressure, and dietary calcium and magnesium intake were associated negatively with blood pressure. No independent significant relationship was found between dietary potassium intake and blood pressure. The results remained essentially unchanged when the dietary cation intake was adjusted per thousand kcal of energy intake.

### Table 3. Univariate Correlation Coefficients Between Dietary and Serum Variables in the Total Group

<table>
<thead>
<tr>
<th>Dietary cation</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>P</th>
<th>Na/K</th>
<th>Ca/P</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men (n=4167)</strong></td>
<td></td>
<td></td>
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<tr>
<td>Na</td>
<td>NS</td>
<td>-0.044*</td>
<td>NS</td>
<td>0.055†</td>
<td>0.045*</td>
<td>-0.052†</td>
<td>NS</td>
</tr>
<tr>
<td>K</td>
<td>-0.040†</td>
<td>-0.036†</td>
<td>NS</td>
<td>0.084†</td>
<td>NS</td>
<td>-0.078†</td>
<td>NS</td>
</tr>
<tr>
<td>Ca</td>
<td>NS</td>
<td>-0.056†</td>
<td>0.034†</td>
<td>0.070†</td>
<td>NS</td>
<td>-0.064†</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Women (n=3891)</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>-0.036†</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-0.041†</td>
</tr>
<tr>
<td>K</td>
<td>-0.067†</td>
<td>NS</td>
<td>-0.037†</td>
<td>0.039†</td>
<td>NS</td>
<td>-0.043*</td>
<td>-0.039†</td>
</tr>
<tr>
<td>Ca</td>
<td>NS</td>
<td>-0.042*</td>
<td>NS</td>
<td>0.083†</td>
<td>0.039†</td>
<td>-0.069†</td>
<td>NS</td>
</tr>
</tbody>
</table>

TP = total protein.
*p < 0.01, †p < 0.001, ‡p < 0.05.

### Discussion

The population studied in Belgium by the BIRNH group is a typical Western population with some regional differences in the intake of fat, the consumption of saturated fat being higher in the southern part of the country and of polyunsaturated fat in the north. This difference has resulted in lower serum cholesterol values in northern Belgium\(^5\) and offers an explanation for the higher mortality in southern Belgium.\(^6\)-\(^10\) Blood pressure levels, however, have always been found to be nearly equal between the regions of Belgium.

The participation rate in the study varied between 35 and 46% in the different counties. This low participation rate is less important for a within-population study, however. In Belgium every citizen is covered by the national health insurance; as a result, the interest in programs directed toward prevention is rather small. Caution, however, should be exerted before the findings of the study are extrapolated to the general population.

In the male population studied by the BIRNH group, the intake of sodium from the diet, excluding table salt and salt added during cooking, amounts to about 110 mmol/day; potassium intake is about 100 mmol/day. The urinary excretion of sodium in Belgium by men is about 160 mmol/24 hr.\(^1\) Thus, the daily added amount of sodium is about 50 mmol (i.e., 30% of the total sodium consumption).

The amount of dietary calcium consumed daily by men was 841 mg (21.0 mmol) in the total group and 852 mg (21.3 mmol) in the group not taking antihypertensive medication, which is higher than the recommended daily allowance of 800 mg/day. The male/female ratio for cation consumption from the diet was 1.46 for sodium, as compared with 1.22 for potassium and 1.36 for total calories consumed. The male/female ratio amounts to 1.07 for sodium and 0.90 for potassium after adjustment for total caloric intake. This finding points to the existence of some differences in the dietary habits of men and women, possibly because more men than women eat outside the home.

Some significant but weak correlations were present between the dietary values and serum values of...
DIETARY ELECTROLYTES AND BLOOD PRESSURE/Kesteloot and Joossens 597

 TABLE 5. Multiple Regression Analysis of SBP and DBP Versus Anthropometric and Dietary Variables in the Total Group

<table>
<thead>
<tr>
<th>BP (mm Hg)</th>
<th>Constant</th>
<th>Age (yr)</th>
<th>BMI (kg/m²)</th>
<th>HR (beats/min)</th>
<th>Na (g/day)</th>
<th>K (g/day)</th>
<th>Ca (g/day)</th>
<th>Mg (g/day)</th>
<th>Alcohol (g/day)</th>
<th>Total intake (kcal/day)</th>
<th>R</th>
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<tbody>
<tr>
<td>Men (n=4167)</td>
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<td>SBP</td>
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<tr>
<td>b</td>
<td>66.7</td>
<td>0.375</td>
<td>1.188</td>
<td>0.273</td>
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<td>—</td>
<td>—</td>
<td>0.020</td>
<td>0.43</td>
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<tr>
<td>b'</td>
<td>—</td>
<td>0.285</td>
<td>0.229</td>
<td>0.170</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.038</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>26.3</td>
<td>19.9</td>
<td>16.2</td>
<td>12.1</td>
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<td>2.7</td>
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<td>DBP</td>
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<tr>
<td>b</td>
<td>39.3</td>
<td>0.085</td>
<td>1.085</td>
<td>0.134</td>
<td>0.556</td>
<td>—</td>
<td>—1129</td>
<td>—</td>
<td>0.020</td>
<td>0.36</td>
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<tr>
<td>b'</td>
<td>—</td>
<td>0.096</td>
<td>0.314</td>
<td>0.125</td>
<td>0.061</td>
<td>—</td>
<td>—0.049</td>
<td>—</td>
<td>0.057</td>
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<td>—3.0</td>
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<td>3.8</td>
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<td>Women (n=3891)</td>
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<td>SBP</td>
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<tr>
<td>b</td>
<td>53.5</td>
<td>0.723</td>
<td>1.094</td>
<td>0.223</td>
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<td>0.231</td>
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<td>—</td>
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<td>0.038</td>
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<tr>
<td>t</td>
<td>19.0</td>
<td>32.5</td>
<td>16.6</td>
<td>9.1</td>
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<tr>
<td>b</td>
<td>40.9</td>
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<td>0.895</td>
<td>0.107</td>
<td>0.591</td>
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<td>—</td>
<td>—0.0009</td>
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</tr>
<tr>
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<td>0.189</td>
<td>0.320</td>
<td>0.096</td>
<td>0.039</td>
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<tr>
<td>t</td>
<td>22.3</td>
<td>12.0</td>
<td>20.6</td>
<td>6.6</td>
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<td>—</td>
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<td>—2.7</td>
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</tbody>
</table>

BP = blood pressure; BMI = body mass index; HR = heart rate; R = multiple correlation coefficient; b = partial regression coefficient; b' = standardized partial regression coefficient; t = t value.

different cations and phosphorus. Under no circumstance, however, was more than 1% of the variation of the serum value explained by the dietary intake of sodium, potassium, or calcium, indicating that this finding is of uncertain clinical importance. On the other hand, the issue may be obscured by the existing day-to-day variability of the diet. More information is also needed about the speed with which the serum cation level reacts to changes in nutritional intake. By multiple regression analysis, several significant correlations were found between dietary cations and blood pressure. Whenever significant, the partial correlation between dietary sodium and blood pressure was positive whereas between dietary calcium and magnesium and blood pressure it was negative. In Western populations, urinary calcium correlates positively with blood pressure, but the relationship between dietary and urinary calcium is complex, as only part of the dietary calcium is absorbed. No significant partial correlation between dietary potassium and blood pressure could be established. In the group not taking antihypertensive medication, within the limits of the dietary intake measured, a difference of 4 SD in the intake of dietary sodium would result in a difference of 2.7 mm Hg in SBP in men and of 2.2 mm Hg in SBP in women and a difference of 3.7 mm Hg in DBP in men. A similar difference in dietary calcium intake would result in a difference of 2.5 mm Hg in DBP in

 TABLE 6. Multiple Regression Analysis of SBP and DBP Versus Anthropometric and Dietary Variables in Subjects Not Taking Antihypertensive Medication

<table>
<thead>
<tr>
<th>BP (mm Hg)</th>
<th>Constant</th>
<th>Age (yr)</th>
<th>BMI (kg/m²)</th>
<th>HR (beats/min)</th>
<th>Na (g/day)</th>
<th>K (g/day)</th>
<th>Ca (g/day)</th>
<th>Mg (g/day)</th>
<th>Alcohol (g/day)</th>
<th>Total intake (kcal/day)</th>
<th>R</th>
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<tbody>
<tr>
<td>Men (n=3814)</td>
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<tr>
<td>b</td>
<td>66.6</td>
<td>0.328</td>
<td>1.129</td>
<td>0.294</td>
<td>0.508</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.024</td>
<td>0.42</td>
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<tr>
<td>b'</td>
<td>—</td>
<td>0.261</td>
<td>0.224</td>
<td>0.191</td>
<td>0.039</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.049</td>
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<tr>
<td>t</td>
<td>24.9</td>
<td>17.0</td>
<td>15.0</td>
<td>12.8</td>
<td>2.5</td>
<td>—</td>
<td>—</td>
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<td>3.2</td>
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<td>DBP</td>
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<tr>
<td>b</td>
<td>39.0</td>
<td>0.074</td>
<td>1.064</td>
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<td>0.709</td>
<td>—</td>
<td>—11.16</td>
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<td>0.024</td>
<td>0.37</td>
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<td>0.086</td>
<td>0.307</td>
<td>0.131</td>
<td>0.079</td>
<td>—</td>
<td>—0.053</td>
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<td>Women (n=3329)</td>
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<td>0.322</td>
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<td>t</td>
<td>21.0</td>
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<td>7.1</td>
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<td>—2.1</td>
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See Table 5 for key to abbreviations.
men and, for dietary magnesium intake, a difference of 4.7 mm Hg in SBP in women. A higher sodium intake increases blood pressure, whereas a higher intake of calcium and magnesium, whenever significant, decreases blood pressure.

In several epidemiological studies, a positive relationship between dietary or urinary 24-hour sodium excretion and blood pressure\(^1\) to \(^16\) and a negative relationship between urinary 24-hour potassium excretion and blood pressure have been found.\(^1\) to \(^14\) In other studies, no significant relationship between 24-hour urinary sodium excretion or 24-hour sodium intake and blood pressure could be established.\(^1\) to \(^17\) In the first National Health and Nutrition Examination Survey in the United States, no significant correlation was found between dietary sodium intake (excluding table salt intake, which was not measured) and blood pressure. The dietary sodium/potassium ratio showed a significant positive correlation with blood pressure, but only in the older age groups.\(^1\) to \(^18\) The absence of a significant negative correlation between dietary potassium and blood pressure in this study is astonishing in view of the high degree of correlation between the dietary intake of potassium and its urinary excretion and since a significant negative correlation is frequently found between urinary 24-hour potassium excretion and blood pressure.\(^1\) to \(^14\) In an American study that also used the 24-hour dietary recording method, a significant positive relationship between dietary sodium intake and the dietary sodium/potassium ratio and a significant negative relationship between dietary potassium and blood pressure were established before and after adjustment for age and dietary variables.\(^19\)

Our findings concerning the relationship between dietary sodium and blood pressure are in general agreement with these American results. In most studies a positive relationship between urinary calcium\(^1\) to \(^12\) and blood pressure and a negative one with urinary magnesium excretion and blood pressure have been established,\(^1\) to \(^12\) but exceptions exist.\(^1\) to \(^14\) The associations between dietary cations and blood pressure established in this study are independent not only of age, body mass index, and heart rate but also of alcohol intake and total caloric intake, two important confounders of the issue.\(^21\) to \(^23\)

A high total caloric intake is associated with a high cation intake, and a high alcohol intake is associated with high blood pressure but a low cation intake. Because of the "noise" produced by the 24-hour food-recording method, and taking into account that the intraindividual variance in sodium intake is higher than the interindividual variance,\(^24\) \(^25\) it is likely that the real effect on blood pressure of dietary sodium is higher than that measured in the present study.

In conclusion, we can state that the data obtained in the BIRNH Study provide confirmatory evidence for the existence of a link between cation intake and blood pressure. This information is of great importance as it pertains to the possibility of influencing blood pressure at the population level by dietary means.

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**References**


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Belgian Interuniversity Research on Nutrition and Health.

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