Dietary electrolyte intake and blood pressure in older subjects: the Rotterdam Study

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Objective To examine the relation between dietary electrolyte intake and blood pressure in older people.

Methods The study included 3239 participants of the Rotterdam Study (41% of the total cohort) who were aged over 55 years and had not been prescribed antihypertensive drugs. Their dietary intake was assessed by a semiquantitative food frequency questionnaire. The association of energy-adjusted intakes of potassium, magnesium and calcium with blood pressure was studied in a linear regression model with adjustment for age, sex, body mass index and alcohol intake.

Results An increase in potassium intake of 1 g/day was associated with a 0.9 mmHg lower systolic and a 0.8 mmHg lower diastolic blood pressure. An increase in magnesium intake of 100 mg was associated with a 1.2 mmHg lower systolic and a 1.1 mmHg lower diastolic blood pressure. Calcium intake was not independently related to blood pressure, except for a subgroup of 1360 hypertensive subjects in which a significant inverse association with diastolic blood pressure was observed.

Conclusions Our findings support the view that an increase in the intake of foods rich in potassium and magnesium could lower blood pressure at older age.

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Introduction

Dietary electrolyte intake could be an important, modifiable determinant of blood pressure level [1,2]. Therapeutic dietary modifications are particularly relevant at older age because more adverse effects of antihypertensive drugs are experienced and compliance with drug therapy often worsens [3,4]. Furthermore, age-associated changes in the cardiovascular system could increase the sensitivity of blood pressure to an inadequate intake of nutrients [5–7]. However, studies concerning the influence of electrolytes on blood pressure at older age are still scarce. We investigated whether blood pressure was related to the intakes of potassium, magnesium and calcium in older participants of the Rotterdam Study.

Methods

The Rotterdam Study

The Rotterdam Study is a population-based study that aims to investigate the occurrence and determinants of chronic disabling diseases at older age [8]. All residents of a suburb of Rotterdam aged over 55 years were invited to participate in the study. A total of 7983 men and women (78%) agreed to participate. During a home interview, information was obtained concerning their current health status, medical history, family history of diseases, education, and income by means of a computerized questionnaire. The participants subsequently visited the study centre for clinical examination and an interview with a dietician. Cross-sectional data of the baseline survey were used for the present analysis.

Blood pressure measurements

Two blood pressure readings were recorded at the study centre and the average is used in the present analysis. Systolic and diastolic (Korotkoff phase V) blood pressures were measured on the right arm using a random-zero sphygmomanometer with a 38 cm × 14 cm cuff, after the participant had been seated for at least 5 min. Data concerning the history of hypertension and use of cardiovascular medication of the subject were obtained during the home interview by means of a questionnaire. A physician checked all packages of medication at the study centre.

Dietary assessment

Before visiting the study centre the participants received a checklist on which they indicated all foods and drinks that they had regularly consumed (i.e. once a month or more often) during the preceding year. The completed checklist was subsequently used as the basis for a detailed interview by a trained dietician at the study centre, who was not informed of the purpose of the present study and who was blinded with regard to the blood pressure levels of the participants. Seasonal variations in diet were taken into account. The dietician registered quantities and frequencies of consumption on a semiquantitative food frequency questionnaire. The questionnaire comprised 170 food items in 13 food groups and was a modified version of a self-administered questionnaire that had been used and validated previously in a large prospective study in the Netherlands [9]. During the course of the study a computerized version of the questionnaire was introduced, which contained multiple checks of the data. The dietician used this computerized questionnaire in 59% of the interviews. Intakes of potassium, magnesium, calcium, alcohol and total energy content were calculated from the food data with the use of Dutch food composition tables [10]. Sodium intake could not be adequately assessed by the food frequency questionnaire.

Population for analysis

A total of 7129 subjects (89% of the total cohort) visited the research centre. No dietary information was obtained from participants of the Rotterdam Study pilot phase (n = 271) and from nursing homes residents (n = 635). Participants who achieved low scores on neuropsychological testing (n = 122) were not interviewed because they were not considered able to recall their dietary intakes adequately. For logistical reasons, a random group of 455 subjects was not interviewed. Diet was thus assessed in 5646 participants. Two hundred and twelve subjects were excluded because they did not fully cooperate during the interview and the dietician did not consider their reported diets reliable. Blood pressure readings were available for 5153 of the remaining participants. Subjects treated with antihypertensive drugs (n = 1587), subjects with a salt-restricted diet (n = 49), subjects who reported regular use of mineral supplements (n = 257) and subjects with incomplete data concerning potential confounders (n = 21) were excluded. In total 3239 participants remained for the present analysis.

Data analysis

Dietary potassium, magnesium and calcium levels were adjusted for energy intake by regressing the electrolyte intakes on total energy and adding the residuals to the mean intakes, as described by Willett *et al.* [11]. Linear regression analyses were performed with systolic and diastolic blood pressures as the dependent variables. Energy-adjusted electrolyte intakes were studied separately and in combination in the multivariate model with adjustment for age, sex, body mass index and alcohol intake. The analyses were repeated in predefined subgroups, namely, men and women, younger and older subjects (below or above the median of the age distribution), and normotensive and hypertensive subjects (blood pressure below or above 140/90 mmHg). Regression coefficients (b) with standard errors (SE) and two-tailed *P*-values. $P < 0.05$ was considered statistically significant.

Results

Characteristics of the study population are shown in Table 1. Of the subjects, 42% (n = 1360) had a systolic blood pressure above 140 mmHg or a diastolic blood pressure above 90 mmHg and 21% (n = 670) reported having been diagnosed hypertensive in the past. Age, body mass index and alcohol intake were significantly associated both with systolic and with diastolic blood pressure. Sex was significantly associated with diastolic blood pressure only (Table 2). Total energy intake, smoking (number of cigarettes per day), education (seven categories) and income (13 categories) were not significantly associated with blood pressure (data not shown).

In Table 3 the relationships of energy-adjusted electrolyte intakes with systolic and diastolic blood pressures are presented. Findings were adjusted for age, sex, body mass index and alcohol intake. Potassium intake was inversely associated with systolic (b = −0.9 mmHg/g potassium, $P = 0.11$) and diastolic blood pressure (−0.8 mmHg/g potassium, $P = 0.01$). The relationship between potassium and diastolic blood pressure was more pronounced in men (−1.2 mmHg/g potassium, $P = 0.01$) than it was in women

Table 1 Characteristics of the study population (n = 3239).

Men (%)	43
Age (years)	66.8 ± 7.6
Systolic blood pressure (mmHg)	136.3 ± 21.4
Diastolic blood pressure (mmHg)	73.0 ± 11.0
Body mass index (kg/m^2)	25.5 ± 3.4
Cigarette smokers (%)	24
Alcohol consumers (%)	81
Dietary intake	
Total energy (kJ/day)	481−146
Alcohol[a] (g/day)	13.7 ± 16.7
Potassium (mg/day)	3700 ± 824
Magnesium (mg/day)	311 ± 75
Calcium (mg/day)	1127 ± 398

Values are expressed as means ± SD or percentages. [a]Alcohol intake among alcohol consumers.

Table 2 Associations of age, sex, body mass index and alcohol intake with blood pressure in 3239 older men and women.

	Systolic blood pressure (mmHg)		Diastolic blood pressure (mmHg)	
	b	*P*	b	*P*
Intercept	59.3		67.3	
Age (years)	0.77 ± 0.05	< 0.0001	−0.10 ± 0.03	< 0.0001
Sex (0 = male, 1 = female)	−0.56 ± 0.76	0.46	−1.50 ± 0.41	< 0.0001
Body mass index (kg/m^2)	0.98 ± 0.10	< 0.0001	0.51 ± 0.06	< 0.0001
Alcohol intake (g/day)	0.07 ± 0.02	0.01	0.03 ± 0.01	0.01

b, Linear regression coefficient ± SE (all variables in model).

Table 3 Associations of energy-adjusted electrolyte intakes with blood pressure in 3239 older men and women.

	Systolic blood pressure (mmHg)		Diastolic blood pressure (mmHg)	
	b	*P*	b	*P*
Separately in model				
Potassium (g/day)	−0.94±0.59	0.11	−0.84±0.31	0.01
Magnesium (mg/day)	−0.012±0.007	0.07	−0.011±0.004	< 0.01
Calcium (g/day)	1.30±1.03	0.21	−0.33±0.55	0.55
Together in model				
Potassium (g/day)	−0.75±0.91	0.41	−0.39±0.66	0.42
Magnesium (mg/day)	−0.018±0.011	0.09	−0.011±0.006	0.06
Calcium (g/day)	3.43±1.24	0.01	0.91±0.66	0.17

b, Linear regression coefficient±SE, adjusted for age, body mass index and alcohol intake.

(−0.5 mmHg/g potassium, $P = 0.25$). For systolic blood pressure, the association was similar in men and in women. Regression coefficients for potassium differed significantly neither between younger and older subjects nor between hypertensives and normotensives. After adjustment for magnesium and calcium intakes, the associations of potassium with blood pressure for the group as a whole were weaker (−0.75 and −0.39 mmHg/g potassium for systolic and diastolic blood pressures, respectively) and no longer statistically significant.

An increase in magnesium intake of 100 mg was associated with a 1.2 mmHg decrease in systolic ($P = 0.07$) and a 1.1 mmHg decrease in diastolic blood pressure ($P < 0.01$). The association of magnesium with systolic blood pressure was more pronounced in men (−1.8 mmHg/100 mg magnesium, $P = 0.06$) than it was in women (−0.9 mmHg/100 mg magnesium, $P = 0.36$). This was also the case for diastolic blood pressure [−1.4 mmHg/100 mg magnesium ($P < 0.01$) in men, compared with −0.8 mmHg/100 mg magnesium ($P = 0.13$) in women]. The associations of magnesium intake with blood pressure were similar in younger and older subjects, and in hypertensives and normotensives. After simultaneous inclusion of potassium and calcium intake in the regression model, the association of magnesium intake with systolic blood pressure for the group as a whole strengthened (−1.8 mmHg/100 mg magnesium, $P = 0.09$), whereas the results for diastolic pressure did not change.

Dietary calcium intake was not significantly independently associated with blood pressure, except for a subgroup of 1360 hypertensive subjects, in whom a significant inverse association of calcium with diastolic blood pressure was observed (−2.2 mmHg/g calcium, $P = 0.01$). Associations of calcium with blood pressure in other subgroups did not differ from the results obtained in the group as a whole. After simultaneous inclusion of potassium and magnesium in the regression model, a significant positive association of calcium intake with systolic blood pressure emerged (3.4 mmHg/g calcium, $P = 0.01$).

When the analyses were repeated with additional adjustment for smoking, education or income the results did not change. Similar results were also obtained when subjects who had reported having been diagnosed hypertensive, but were not currently receiving treatment with antihypertensive drugs, were excluded from the analyses.

Discussion

Within the older population of the Rotterdam Study, dietary potassium and magnesium intakes were inversely and independently related to systolic and diastolic blood pressures after adjustment for age, sex, body mass index and alcohol intake. Calcium intake showed no independent relationship with blood pressure, except in hypertensive subjects, in whom a significant inverse association with diastolic blood pressure was observed. When all electrolytes were considered together in the regression model, potassium and magnesium intakes retained their inverse association with systolic and diastolic blood pressures. However, a significant positive association with systolic blood pressure emerged for calcium intakes.

Some limitations of the study need to be discussed. First, we could not study the effect of sodium intake, because salt use during cooking and dining could not be adequately assessed by the questionnaire used in our study. A diet rich in fruit and vegetables, which are the main sources of potassium and magnesium, is generally a healthy diet that contains fewer fatty and salty foods. The observed inverse associations of potassium and magnesium intake with blood pressure could therefore result partially from a low intake of sodium. Secondly, it should be noted that our choice of study population might have influenced the strength of the observed associations. Subjects who are expected to be most vulnerable to an inadequate electrolyte intake, or to an unhealthy lifestyle in general, may have died before reaching old age or have been prescribed antihypertensive drugs. Such people were proportionately less well represented in our study. Finally, when nutrients are studied in relation to disease it is difficult to exclude confounding influences completely. Dietary patterns are closely related to other factors that may also influence blood pressure, such as age, alcohol consumption, body weight, education and physical activity. We considered most of these variables in our analyses, but could not adjust for physical activity. This could have given rise to residual confounding, because a healthy lifestyle with regular physical activity is associated with a higher intake of potassium and magnesium through fruits and vegetables, and with lower blood pressure levels. However, the total energy intake, which is correlated with physical activity [12], was not associated with blood pressure in our older population.

Studies concerning potassium intake and blood pressure in older people are scarce. The potassium content of the diet has been related to blood pressure in a number of observational studies of middle-aged men and women, but findings are inconsistent [13,14]. Cappuccio and MacGregor [15] summarized 19 published trials concerning the effect of potassium supplementation on blood pressure. Blood pressure reductions of 5.9 mmHg systolic and 3.4 mmHg diastolic were observed with an average, substantial increase in potassium intake of 86 mmol/day (3.4 g/day). A significant dose–response relationship between change in diastolic blood pressure and 24 h urinary potassium excretion was reported recently in the Trials of Hypertension Prevention (TOHP) [16], but the effect on blood pressure was small (−1.5 mmHg for the highest versus the lowest quartile of change in urinary potassium level). In a trial in hypertensive elderly subjects [17], potassium supplementation resulted in a significant reduction in blood pressure, which is in accord with the results of our study. We found that lower potassium intakes were observed in subjects with higher blood pressure levels. This suggests that blood pressure levels in the elderly respond adversely to an inadequate intake of potassium.

We observed an inverse relationship of magnesium with systolic and diastolic blood pressures. Some other large population studies [18,19] suggested that magnesium intake plays a role in determining blood pressure. A trial in middle-aged and older Dutch women [20] showed a 3.4 mmHg decrease in diastolic blood pressure when their daily magnesium intake was doubled. However, the TOHP [21] could not achieve a blood pressure reduction after 3 or 6 months of intervention with magnesium supplements in middle-aged adults. Possibly, the effect of magnesium on blood pressure becomes apparent only at older age, which could explain the inverse association between magnesium intake and blood pressure in our study. An alternative explanation for our findings could be the strong association of magnesium intake with intake of fibre, an agent that might also lower blood pressure.

Many observational studies [2,22] have reported an inverse association between calcium intake and blood pressure, although negative results have also been reported [23]. We observed an independent relationship of calcium intake only with diastolic blood pressure in hypertensive subjects. Possibly, the sensitivity of blood pressure to calcium intake increases with blood pressure level. Drug-treated hypertensive subjects were removed from our analysis, which may explain why no relation was observed in the group as a whole. Furthermore, the majority of our subjects had an adequate intake of calcium, whereas other studies that showed an inverse association with blood pressure reported lower calcium intakes. An unexpected positive relationship of calcium intake with systolic blood pressure emerged after adjustment for potassium and magnesium intake. Because the association was not consistent and contrasts with findings in previous studies, this probably resulted from multicollinearity. This problem occurs when the variation in one variable is substantially reduced because of the inclusion of one or more other variables. Possibly, the relationship estimated from the residual variation after removing the effect of potassium and magnesium intakes is not attributable to calcium intake itself but to other factors that are associated with calcium intake rather than with potassium and magnesium intakes. The intake of saturated fat, for example, is correlated with calcium intake through consumption of dairy products and might have given rise to the unexpected, positive relationship with blood pressure. Nevertheless, we cannot exclude that the influence of calcium on blood pressure is different at advanced age as a result of age-related changes in biological mechanisms. A positive association between calcium and blood pressure in elderly Chinese subjects was reported by Woo *et al.* [24].

The complexity of the human diet makes it difficult to separate the effect of any specific nutrient from possible effects of other nutrients. The intake of potassium is highly correlated with that of magnesium because the two elements are often ingested together in the same vegetables and fruits. The problem of multicollinearity cannot be resolved by statistical methods. The simultaneous inclusion of strongly correlated variables in a multivariate regression model might give rise to unanticipated, spurious results. In our study, this was probably the case when dietary potassium and magnesium intakes were included in the multivariate model together with dietary calcium intake. Although our data are compatible with there being independent effects of potassium and magnesium intake, inferences from observational studies should probably consider mixtures of nutrients rather than individual factors. Our findings suggest that an increase in the intake of foods rich in potassium and magnesium could lower blood pressure in the elderly.

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