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Association of Urinary Sodium and Potassium Excretion with Blood Pressure

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ABSTRACT

BACKGROUND

Higher levels of sodium intake are reported to be associated with higher blood pressure. Whether this relationship varies according to levels of sodium or potassium intake and in different populations is unknown.

METHODS

We studied 102,216 adults from 18 countries. Estimates of 24-hour sodium and potassium excretion were made from a single fasting morning urine specimen and were used as surrogates for intake. We assessed the relationship between electrolyte excretion and blood pressure, as measured with an automated device.

RESULTS

Regression analyses showed increments of 2.11 mm Hg in systolic blood pressure and 0.78 mm Hg in diastolic blood pressure for each 1-g increment in estimated sodium excretion. The slope of this association was steeper with higher sodium intake (an increment of 2.58 mm Hg in systolic blood pressure per gram for sodium excretion >5 g per day, 1.74 mm Hg per gram for 3 to 5 g per day, and 0.74 mm Hg per gram for <3 g per day; P<0.001 for interaction). The slope of association was steeper for persons with hypertension (2.49 mm Hg per gram) than for those without hypertension (1.30 mm Hg per gram, P<0.001 for interaction) and was steeper with increased age (2.97 mm Hg per gram at >55 years of age, 2.43 mm Hg per gram at 45 to 55 years of age, and 1.96 mm Hg per gram at <45 years of age; P<0.001 for interaction). Potassium excretion was inversely associated with systolic blood pressure, with a steeper slope of association for persons with hypertension than for those without it (P<0.001) and a steeper slope with increased age (P<0.001).

CONCLUSIONS

In this study, the association of estimated intake of sodium and potassium, as determined from measurements of excretion of these cations, with blood pressure was nonlinear and was most pronounced in persons consuming high-sodium diets, persons with hypertension, and older persons. (Funded by the Heart and Stroke Foundation of Ontario and others.)

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Hypertension affects 1 billion people and is considered to be a leading cause of death, stroke, myocardial infarction, congestive heart failure, and chronic renal impairment.[1-4] Sodium intake is reported to be a modifiable determinant of hypertension.[5,6] The International Study of Salt and Blood Pressure (INTERSALT),[7] but not another large study,[8] showed a modest association between higher levels of sodium intake and higher blood pressure. However, INTERSALT was not large enough to determine whether the association varied according to region, participant characteristics, or levels of sodium or potassium intake. Substantially larger studies are needed to assess the shape of the association between sodium intake and blood pressure and to determine whether the association differs among different populations and regions of the world.

A Quick Take animation is available at NEJM.org

We investigated these questions within the Prospective Urban Rural Epidemiology (PURE) study, an established large, international, prospective, epidemiologic study.[9] Our aims were, first, to estimate the levels of sodium and potassium intake (on the basis of urinary-excretion data) overall and according to urban versus rural area, country income level, and geographic region and, second, to describe their associations with blood pressure, overall and in key subgroups.

Methods

Study Design and Participants

The PURE study enrolled 157,543 adults 35 to 70 years of age from 667 communities in 18 low-, middle-, and high-income countries on 5 continents[9,10] (for details on participant selection, see the Methods section in the Supplementary Appendix, available with the full text of this article at NEJM.org). Countries were selected from four income strata according to the World Bank classification in 2006 on the basis of gross national income per capita: 4 low-income countries (Bangladesh, India, Pakistan, and Zimbabwe), 4 lower-middle-income countries (China, Colombia, Iran, and the Occupied Palestinian Territory), 7 upper-middle-income countries (Argentina, Brazil, Chile, Malaysia, Poland, South Africa, and Turkey), and 3 high-income countries (Canada, Sweden, and the United Arab Emirates). The final study sample comprised 102,216 participants with a valid baseline fasting morning urine sample, of whom 42% were from China. Baseline characteristics of the participants in our study were generally similar to the characteristics of the participants in the overall PURE study (Table 1).

Study Procedures

On arrival at the clinic in the morning, each participant provided a fasting midstream urine specimen, which was frozen at −20 to −70°C. All samples were shipped in ambient packaging with the use of STP-250 shipping boxes (Saf-T-Pak) to the Clinical Research and Clinical Trials Laboratory at Hamilton General Hospital in Hamilton, Ontario, Canada (the central laboratory for 15 countries), or to a regional laboratory in Beijing; Bangalore, India; or Kocaeli, Turkey, for analyses with the use of standardized methods. Physical assessment of each participant included weight, height, and two recordings of resting blood pressure with the use of the Omron HEM-757 automatic digital monitor (Omron Healthcare). The methods used to perform urinary analyses and blood-pressure measurements are described in the Methods section in the Supplementary Appendix. Information on medical history and use of medications was recorded.

We used the Kawasaki formula[11,12] to estimate 24-hour urinary excretion of sodium and potassium from a fasting morning specimen and used these estimates as surrogates for sodium and potassium intake. A validation study of the Kawasaki formula involved 1083 people from 11 countries (Fig. S1 and S2 and Table S1 in the Supplementary Appendix).[13] This study showed an intraclass correlation coefficient of 0.71 (95% confidence interval [CI], 0.65 to 0.76) for the Kawasaki estimate versus measured 24-hour sodium excretion. In another analysis from the same study, the mean blood pressure level at varying levels of sodium excretion was similar for Kawasaki-estimated and 24-hour measured excretion (for systolic blood pressure, 127.4 mm Hg and 128.3 mm Hg, respectively, at <3 g of sodium per day; 129.0 mm Hg and 129.5 mm Hg at 3 to 5 g per day; and 137.7 mm Hg and 135.0 mm Hg at >5 g per day), and the relationship of both measures with blood pressure was also similar ($P<0.001$ for each trend).[13]

Study Oversight and Conduct

The study was designed by the last author and was supervised by the third and last authors to-

Table 1. Characteristics of the Participants in the Sodium Study and the Overall PURE Study Cohort.*

Characteristic	Sodium Study (N=102,216)	Overall Study (N=157,543)
Sodium excretion — g/day†	4.93±1.73	
Potassium excretion — g/day†	2.12±0.60	
Creatinine excretion — g/day‡	1.30±0.37	1.27±0.38
Country income level — no. (%)		
Low income	7,293 (7.1)	34,984 (22.2)
India only	4,902 (4.8)	29,044 (18.4)
Lower middle income	54,737 (53.6)	62,443 (39.6)
China only	43,042 (42.1)	47,200 (30.0)
Upper middle income	25,705 (25.1)	44,000 (27.9)
High income	14,481 (14.2)	16,116 (10.2)
Age — yr	51.0±9.7	50.6±9.9
Female sex — no. (%)	58,464 (57.2)	90,783 (57.6)
Educational level — no./total no. (%)		
Less than high-school graduate	41,861/101,833 (41.1)	66,994/156,547 (42.8)
High-school graduate	38,624/101,833 (37.9)	59,705/156,547 (38.1)
Some college or more	21,348/101,833 (21.0)	29,848/156,547 (19.1)
Body-mass index§	26.1±5.1	25.8±5.2
Waist-to-hip ratio	0.87±0.08	0.87±0.09
Tobacco use — no./total no. (%)		
Never	66,319/101,324 (65.5)	105,040/155,971 (67.3)
Former	13,771/101,324 (13.6)	18,198/155,971 (11.7)
Current	21,234/101,324 (21.0)	32,733/155,971 (21.0)
Level of physical activity — no./total no. (%)		
Low	13,423/95,188 (14.1)	23,003/141,835 (16.2)
Medium	37,247/95,188 (39.1)	55,194/141,835 (38.9)
High	44,518/95,188 (46.8)	63,638/141,835 (44.9)
Alcohol consumption — no./total no. (%)		
Never drank	66,185/101,582 (65.2)	110,662/156,404 (70.8)
Former drinker	4766/101,582 (4.7)	6867/156,404 (4.4)
Current drinker	30,631/101,582 (30.2)	38,875/156,404 (24.9)
Diabetes — no./total no. (%)	7200/102,056 (7.1)	12,782/157,051 (8.1)
Blood pressure — mm Hg		
Systolic	131.7±21.5	131.4±21.5
Diastolic	81.9±12.2	81.7±12.2
Self-reported hypertension or blood pressure ≥140/90 mm Hg — no./total no. (%)	42,978/102,216 (42.0)	63,750/157,288 (40.5)
Blood pressure ≥140/90 mm Hg	35,521/102,216 (34.8)	50,348/147,047 (34.2)
Coronary heart disease — no./total no. (%)	4772/102,027 (4.7)	6138/157,000 (3.9)
Stroke — no./total no. (%)	1925/102,029 (1.9)	2619/157,016 (1.7)
Congestive heart failure — no./total no. (%)	877/96,536 (0.9)	1290/142,362 (0.9)
Cardiovascular disease — no./total no. (%)	8637/102,069 (8.5)	11,619/157,020 (7.4)
Blood-pressure medication — no. (%)	14,856 (14.5)	19,465 (12.4)
Statin medication — no. (%)	3,475 (3.4)	4,386 (2.8)

* Plus–minus values are means ±SD. The characteristics of the participants in the sodium study were generally similar to those of the overall Prospective Urban Rural Epidemiology (PURE) study cohort.
† Estimated excretion was determined from a fasting morning urine specimen on the basis of the Kawasaki formula.
‡ Creatinine excretion was estimated according to a formula that includes age, sex, weight, and height and that was used by Kawasaki et al.[11] in their formula to estimate sodium and potassium excretion.
§ The body-mass index is the weight in kilograms divided by the square of the height in meters.

gether with the designated leader in each country (see the Supplementary Appendix). All analyses were performed by the first author. The first author assumes responsibility for the analyses and interpretation of data and wrote the first draft of the manuscript with the second and last authors.

The PURE study was funded by nonprofit, government, and industry sponsors. The funders of the study had no role in its design or conduct, in the collection, analysis, or interpretation of the data, or in the writing of the manuscript. The study was approved by the ethics committees at all participating centers and at Hamilton Health Sciences, Hamilton, Ontario, Canada. All participants provided written informed consent.

STATISTICAL ANALYSIS

Mean (±SD) estimated sodium excretion and potassium excretion were computed for the entire cohort and according to sex, urban versus rural area, country income level, and geographic region (Africa, China, Malaysia, the Middle East, North America and Europe, South America, and South Asia), with adjustment for age and sex where appropriate. Multivariable linear regression was used to assess the association between electrolyte excretion and blood pressure. We calculated the difference in systolic and diastolic blood pressure per 1 g (43.5 mmol) of sodium excretion or 1 g (25.6 mmol) of potassium excretion. Participants were categorized into groups on the basis of increments of 1 g per day in urinary sodium excretion and increments of 0.25 g per day in potassium excretion. Analysis of covariance was performed, with tests for linear trend, to compare the mean blood pressure among groups defined on the basis of sodium excretion or potassium excretion, with adjustment for covariates known to be associated with blood pressure, including age, sex, educational level, body-mass index, alcohol intake, and geographic region. In assessing associations of sodium excretion with blood pressure, we investigated the influence of age, geographic location, hypertension status, alcohol intake, body-mass index, and potassium excretion, using tests of interaction. The effect of sodium or potassium excretion on blood pressure was further evaluated at different levels of sodium or potassium excretion.

To explore the effect of regression dilution bias, we conducted a secondary analysis using the estimated "usual" excretion of sodium and potassium, as described by the Prospective Studies Collaboration[14] (the regression dilution ratio was calculated on the basis of baseline measurement and remeasurement at 30 to 90 days in 448 participants). We used linear regression to assess the association of the urinary sodium-to-potassium ratio with blood pressure, adjusting for the same covariates. Statistical analyses were conducted with the use of SAS software, version 9.3 (SAS Institute).

RESULTS

CHARACTERISTICS OF THE STUDY PARTICIPANTS

The characteristics of the 102,216 participants are shown in Table 1, and in Tables S2 and S3 in the Supplementary Appendix. Mean sodium excretion was estimated to be 4.93±1.73 g, and mean potassium excretion was estimated to be 2.12±0.60 g, with higher excretion in men than in women (P<0.001 for sodium and potassium).

PATTERNS OF SODIUM AND POTASSIUM EXCRETION

Overall, 43.5% of the population had an estimated sodium excretion of more than 5 g per day, 45.9% between 3 and 5 g per day, and 10.6% less than 3 g per day (3.3% had an excretion <2.3 g per day, and 0.6% <1.5 g per day). After adjustment for regression dilution bias, 2.1% of participants had an estimated sodium excretion of less than 3 g per day, and only 0.2% had excretion of less than 2.3 g per day (Fig. 1A). Overall, 7.9% of participants had an estimated potassium excretion of more than 3 g per day (Fig. 1B).

Estimated sodium excretion was higher in rural areas than in urban areas (P<0.001), whereas estimated potassium excretion was higher in urban areas (P<0.001) (Tables S2 and S3 in the Supplementary Appendix). Per capita gross national income was inversely associated with estimated sodium excretion and positively associated with estimated potassium excretion (P<0.001 for trends). Mean estimated sodium excretion ranged from 3.78 g per day in Malaysia to 5.59 g per day in China. Mean estimated potassium excretion ranged from 1.70 g per day in South Asia (Bangladesh, India, and Pakistan) to 2.46 g per day in Canada and Europe (Poland and Sweden).

URINARY SODIUM EXCRETION AND BLOOD PRESSURE

After adjusting for covariates, we found a significant positive association between estimated

sodium excretion and systolic blood pressure (P<0.001 for trend) and between estimated sodium excretion and diastolic blood pressure (P<0.001 for trend) (Fig. 2A and 2B). For each 1-g increment in estimated sodium excretion, there was an increment of 1.46 mm Hg in systolic blood pressure (P<0.001) and an increment of 0.54 mm Hg in diastolic blood pressure (P<0.001). After correcting for regression dilution bias and adjusting for covariates, we observed a steeper slope (a larger increment in blood pressure for a 1-g increment in estimated sodium excretion) for the association between estimated usual sodium excretion and blood pressure, with an increment of 2.11 mm Hg in systolic blood pressure per gram and an increment of 0.78 mm Hg in diastolic blood pressure per gram (P<0.001 for both comparisons).

The positive relationship between sodium excretion and blood pressure was observed in all geographic regions. The slope of the association, however, was less steep in the Middle East (Iran, Turkey, the United Arab Emirates, and the Occupied Palestinian Territory) than in most of the other regions studied (P<0.001 for interaction).

The relationship of estimated sodium excretion with systolic blood pressure was nonlinear, with a significantly steeper slope for the association at a level of sodium excretion of more than 5 g per day (2.58 mm Hg per gram of sodium; 95% CI, 2.38 to 2.78; P<0.001 for the comparison of the slope with a slope of 0) than at a level of excretion of 3 to 5 g per day (1.74 mm Hg per gram; 95% CI, 1.29 to 2.19; P<0.001) or less than 3 g per day (0.74 mm Hg per gram; 95% CI, −0.36 to 1.84; P=0.19) (P<0.001 for interaction) (Fig. 2A and 3A). Similar results were observed for diastolic blood pressure (P<0.001 for interaction) (Fig. 2B and 3B).

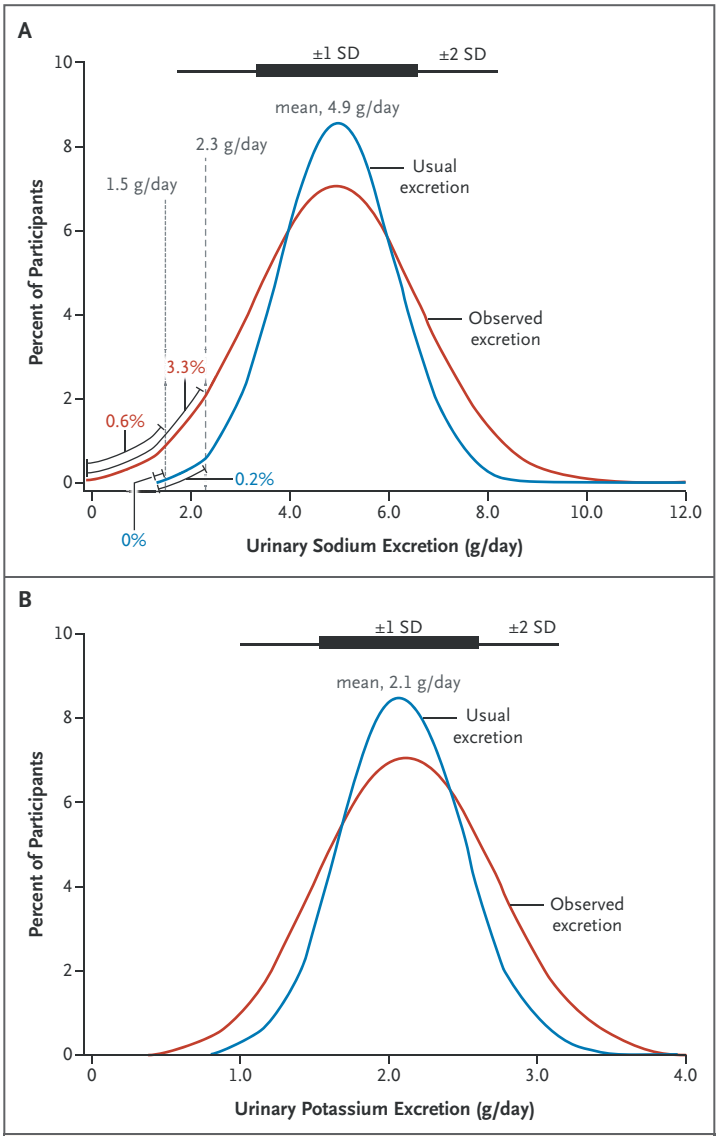

Figure 1. Distribution of Sodium and Potassium Excretion in 102,216 Study Participants.

Observed excretion from a single fasting morning urine specimen and estimated "usual" excretion (after adjustment for regression dilution bias) are shown. For observed excretion, the mean (±SD) sodium excretion was 4.93±1.73 g per day; 3.3% of participants had sodium excretion of less than 2.30 g per day, and 0.6% of participants had sodium excretion of less than 1.50 g per day. For estimated usual excretion, the mean sodium excretion was 4.90±1.17 g per day; 0.2% of participants had sodium excretion of less than 2.30 g per day, and none had sodium excretion of less than 1.50 g per day.

URINARY POTASSIUM EXCRETION AND BLOOD PRESSURE

A significant inverse association between estimated potassium excretion and systolic blood pressure was observed after adjustment for covariates (P<0.001) (Fig. S3 in the Supplementary Appendix). For each increment of 1 g in estimated potassium excretion per day, there was a decrement of 0.75 mm Hg in systolic blood pressure (P<0.001) and a decrement of 0.06 mm Hg in diastolic blood pressure (P=0.33). The decrements were larger after correction for regression dilution bias (1.08 mm Hg and 0.09 mm Hg, respectively). There was a stronger inverse relationship between potassium excretion and blood pressure in China than in the other geographic regions studied (P<0.001 for interaction).

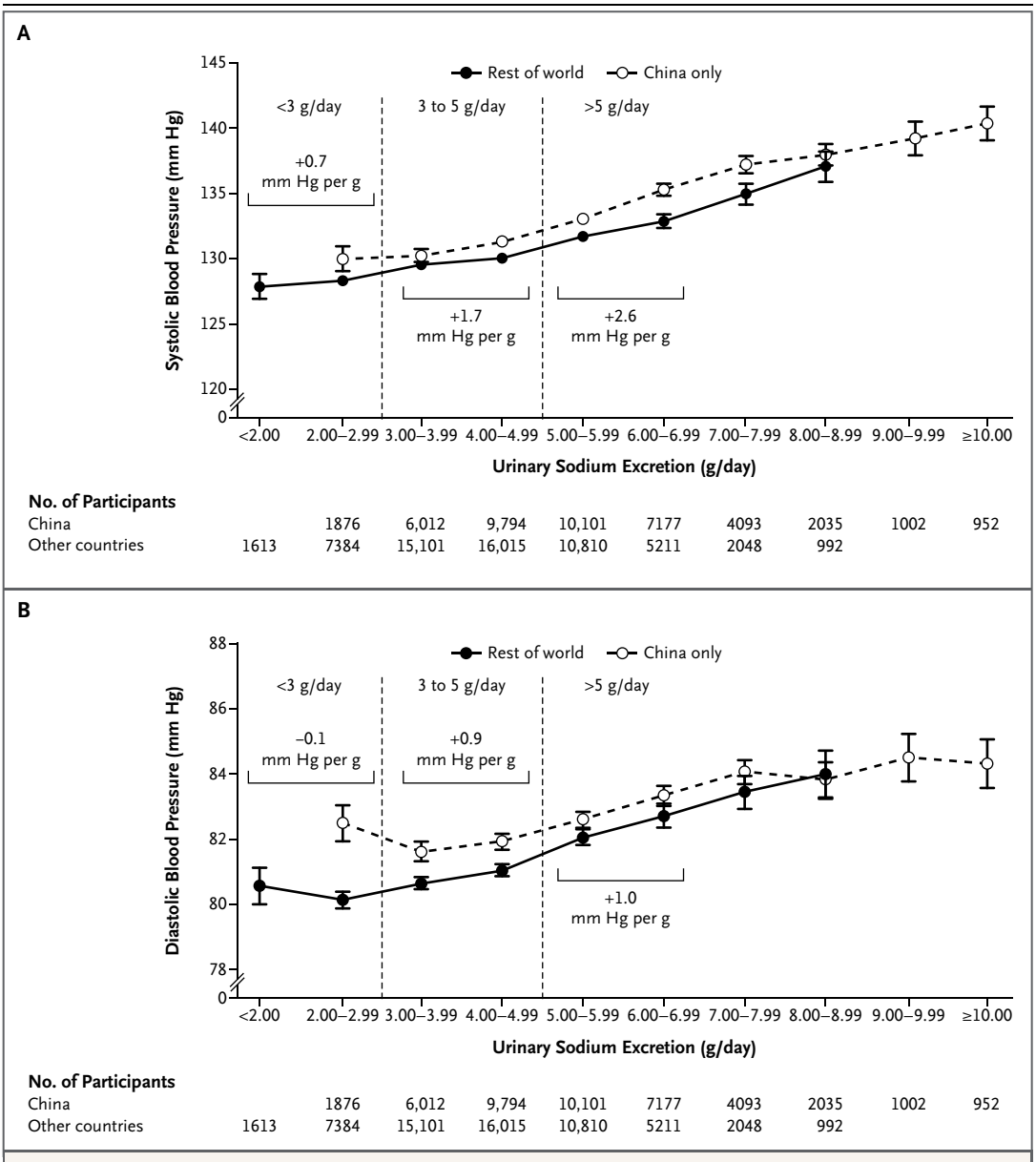

Figure 2. Mean Systolic and Diastolic Blood Pressure According to Sodium Excretion.

The analysis was adjusted for age, sex, body-mass index, educational level, alcohol intake, and geographic region. Changes in blood pressure are shown for sodium excretion of less than 3 g per day, excretion of 3 to 5 g per day, and excretion of more than 5 g per day. Persons with extremely low or extremely high sodium excretion are included in the figure. In China, 218 persons with excretion of less than 2 g per day were included in the group with excretion of 2.00 to 2.99 g per day, and 482 persons with excretion of more than 11 g per day were included in the group with excretion of 10.00 g or more per day. In other countries, 235 persons with excretion of 9.00 to 9.99 g per day and 112 persons with excretion of 10 g or more per day were included in the group with excretion of 8.00 to 8.99 g per day. I bars indicate 95% confidence intervals.

SODIUM-TO-POTASSIUM RATIO AND BLOOD PRESSURE

After adjustment for covariates, a strong and linear association was observed between the estimated sodium-to-potassium ratio and systolic blood pressure (P<0.001 for trend) and between the sodium-to-potassium ratio and diastolic blood pressure (P<0.001 for trend), although the slope of this association was significantly steeper in China than in other countries (P<0.001 for interaction). A 1-SD increment in the estimated sodium-to-potassium ratio (of 3.26) was associated with increments of 2.30 mm Hg in systolic blood pres-

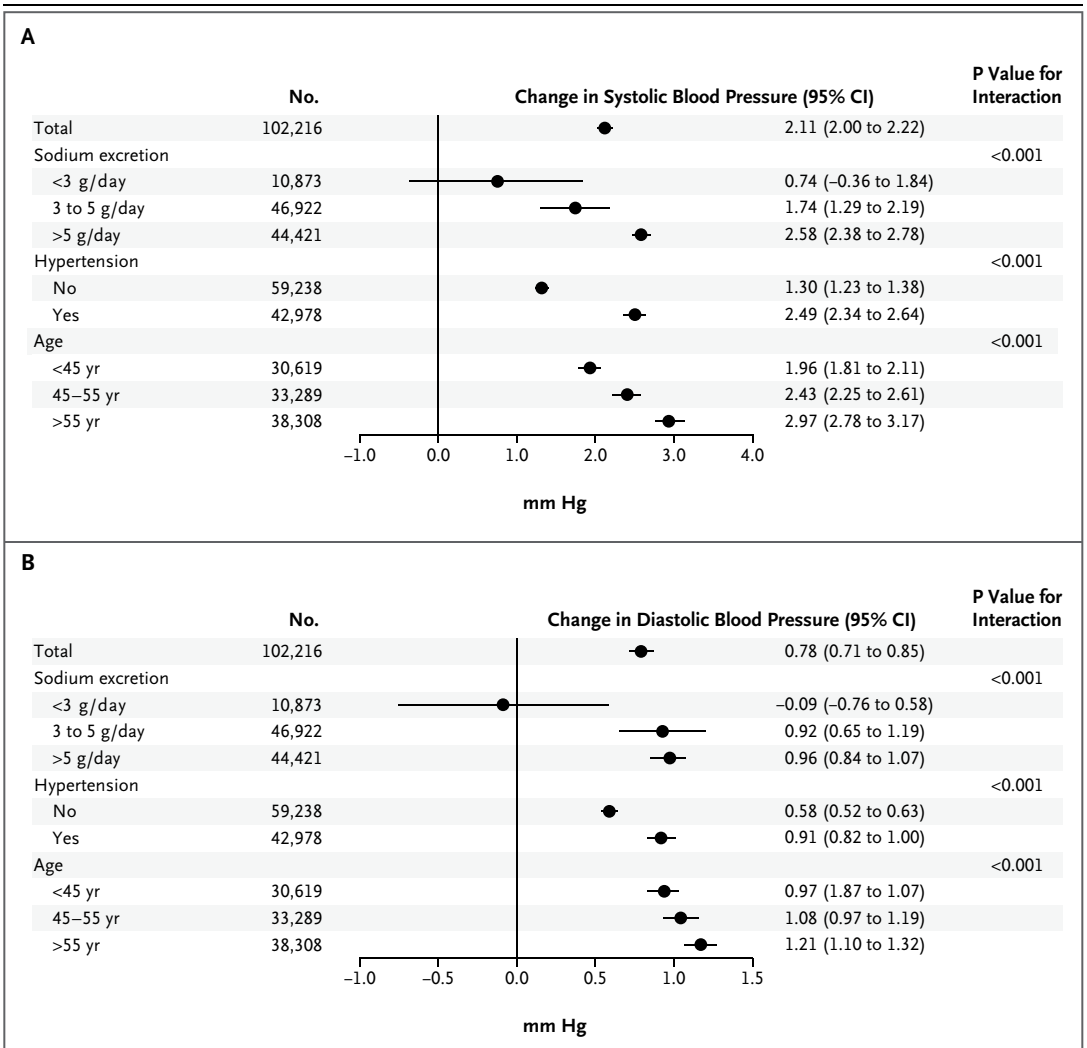

Figure 3. Forest Plots of Changes in Systolic and Diastolic Blood Pressure for Every 1-g Increase in Sodium Excretion.
Data are based on multivariable linear regression models with adjustment for covariates and regression dilution bias.

sure and 0.78 mm Hg in diastolic blood pressure (P<0.001 for both comparisons). The highest blood pressures were observed in the group with the highest estimated sodium excretion and the lowest estimated potassium excretion (difference from group with lowest sodium excretion and highest potassium excretion, 12 mm Hg in systolic pressure and 5 mm Hg in diastolic pressure; P<0.001 for interaction) (Fig. 4).

SENSITIVITY AND SUBGROUP ANALYSES

Exclusion of the 8637 participants with cardiovascular disease (who had an increment of 2.11 mm Hg in systolic blood pressure per 1-g increment in sodium excretion), the 14,856 participants receiving antihypertensive therapy (who had an increment of 2.24 mm Hg per gram), or the 43,042 participants from China (who had an increment of 2.10 mm Hg per gram) did not materially alter the findings of association. Estimated sodium excretion was more strongly associated with increased systolic and diastolic blood pressure in persons with hypertension (increment of 2.49 mm Hg in systolic pressure per gram) than in those without hypertension (1.30 mm Hg in systolic pressure per gram; P<0.001 for interaction) (Fig. 3A and 3B). There was also a significant trend according to age, with a steeper slope of association with estimated sodium excretion in persons older than 55 years of age (2.97 mm Hg in systolic pressure per gram) than in those 45 to 55 years of age (2.43 mm Hg per gram) or those

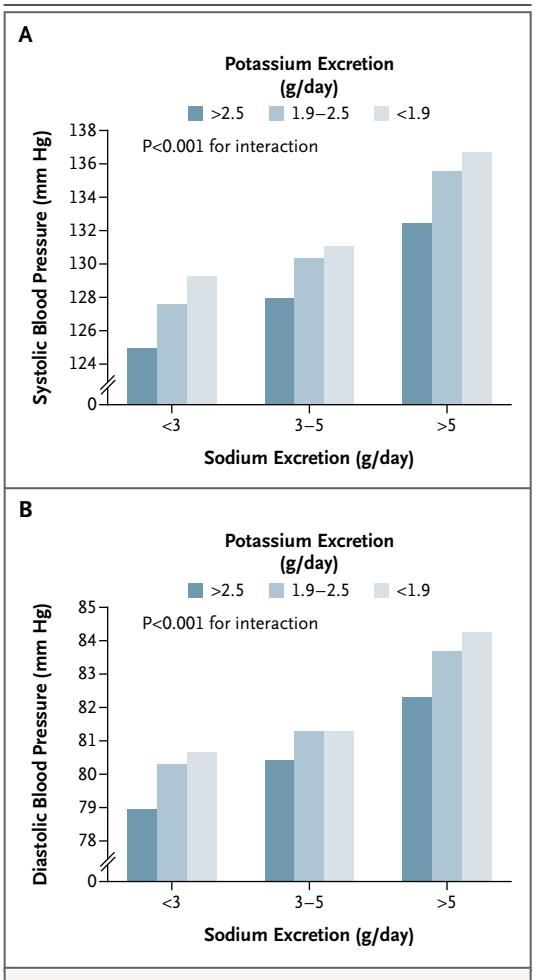

Figure 4. Mean Systolic and Diastolic Blood Pressure According to Sodium and Potassium Excretion.

Adjustment was made for age, sex, geographic region, body-mass index, educational level, and alcohol intake. The P value for interaction is for testing the joint effect of the two electrolytes on blood pressure.

younger than 45 years of age (1.96 mm Hg per gram; P<0.001 for interaction) (Fig. 3A and 3B). Higher estimated potassium excretion was associated with a steeper inverse relationship with systolic and diastolic blood pressure among persons with increased levels of estimated sodium excretion, as well as among older persons, those with hypertension, and those with an increased body-mass index (P<0.001 for interaction for all comparisons).

DISCUSSION

In this study of 102,216 adults from 18 countries and 5 continents, we found a positive but nonuniform association between estimated sodium excretion and blood pressure. We found a steep slope for this association among study participants with sodium excretion of more than 5 g per day, a modest association among those with sodium excretion of 3 to 5 g per day, and no significant association among those with sodium excretion of less than 3 g per day. Furthermore, the slope of the association was steeper among persons with hypertension than among those without hypertension and was steeper with increasing age. For estimated potassium excretion, we found a significant inverse association with systolic blood pressure, with steep slopes of association among persons with hypertension, older persons, and obese persons.

In the PURE study, the slope of the overall relationship between estimated sodium excretion and blood pressure was substantially steeper than that reported in INTERSALT (increments of 1.46 mm Hg in systolic pressure per gram and 0.54 mm Hg in diastolic pressure per gram vs. increments of 0.94 mm Hg per gram and 0.03 mm Hg per gram, respectively). Unlike INTERSALT, the PURE study included persons older than 59 years of age, and it had a larger cohort from China (42% of all participants vs. 6%), where the average estimated sodium excretion was higher than in other countries (5.59 g per day vs. 4.45 g per day). However, when we excluded China and restricted our analyses to persons younger than 60 years of age, the increments did not change substantially (1.24 mm Hg in systolic pressure per gram of sodium and 0.63 mm Hg in diastolic pressure per gram).

Current guidelines recommend a maximum sodium intake of 1.5 to 2.4 g per day.[15] These recommendations are based on short-term trials showing a modest reduction in blood pressure with reduced dietary sodium. Most of these trials considered the amount of the reduction in sodium intake but not the baseline level of sodium intake.[16] The Dietary Approaches to Stop Hypertension (DASH) trial[17] showed a more marked blood-pressure reduction in participants who reduced their sodium intake over a 30-day period from 2.5 g per day to 1.5 g per day than in those who reduced their intake from 3.3 g per day to 2.5 g per day. However, the DASH study differed from the PURE study in numerous respects, other than study design. More than 50% of participants in the DASH study had hypertension or prehypertension, more than 50% of participants were of African ancestry, potassium intake was markedly

lower than in the general U.S. population, the trial involved only 412 persons, and a limited range of sodium intake was studied (1.5 to 3.3 g per day). In the PURE study, very few participants had an estimated sodium intake of less than 2.3 g per day, and almost none had an intake of less than 1.5 g per day. This suggests that, at present, human consumption of extremely low amounts of sodium for prolonged periods is rare.

Persons with hypertension had larger increases in blood pressure per 1-g increment of estimated sodium excretion than normotensive persons, a finding that is consistent with those of a recent meta-analysis of trials involving a sodium-reduction intervention.[16] Our finding of a steeper slope of association among older persons than among younger persons is also compatible with previous data, such as those from INTERSALT.[7]

The significant inverse relationship between estimated potassium excretion and blood pressure is consistent with the results of INTERSALT (decrements of 0.65 mm Hg in systolic pressure per gram of potassium and 0.42 mm Hg in diastolic pressure per gram),[7] population studies in the United States[18,19] and Europe,[8] and a recent review.[20] In the DASH trial, the effects of sodium were modified by the amount of potassium in the diet.[17] Similarly, we found that high estimated sodium excretion, when combined with low estimated potassium excretion, was associated with markedly higher blood pressure than either high estimated sodium excretion alone or low estimated potassium excretion alone and was associated with substantially higher blood pressure than was low estimated sodium excretion with high estimated potassium excretion. These findings suggest that the effect of sodium on blood pressure is dependent on the background diet.[21]

One potential limitation of our study may be the method of estimating sodium and potassium intake from a fasting morning urine specimen and using a formula-derived estimate of 24-hour urinary excretion. In our validation study, we found an intraclass correlation coefficient of 0.71 between our method and actual 24-hour measures of urinary sodium. With our method, there is a 10% overestimation of 24-hour sodium excretion, indicating that the true intake range at which the strength of the association between sodium intake and blood pressure changes may occur at a slightly lower level of sodium intake (a finding that is also relevant to the article by O'Donnell et al.[22] in this issue of the *Journal*). In our validation study, the Kawasaki formula was found to be more reliable than two other methods for estimating 24-hour urinary sodium excretion (the INTERSALT method and the Tanaka method).[11-13] Actual measurement of 24-hour urinary excretion, with repeated measurement to determine usual intake (i.e., to account for day-to-day variability), would be ideal. However, such an approach is impractical for large-scale efforts such as the PURE study. Our approach is probably less reliable for estimating potassium intake than for estimating sodium intake, because the proportion of consumed potassium that is excreted in the urine is lower than the proportion of consumed sodium that is excreted.[23]

Another potential limitation of our study is that a true probability-sampling approach was not undertaken to select our study population. Such a method was not feasible, given the constraints of studying sodium excretion in a wide range of countries and settings. Furthermore, low-income countries were underrepresented in the final study sample, because a considerable proportion of urine samples in India had to be discarded owing to prolonged storage in suboptimal conditions. However our approach should not compromise the magnitude and shape of association between estimated sodium excretion and blood pressure among the study participants. Moreover, given its epidemiologic nature, our study did not measure the effect of changing sodium and potassium intakes. However, our findings do suggest that assessments of the relationship between sodium intake and blood pressure should take into account the level of sodium intake in the population, the age of the participants, and whether the participants have hypertension.

In conclusion, our study of estimated sodium and potassium excretion, as a surrogate for intake, and blood-pressure recordings in 102,216 adults from 18 countries showed a nonlinear association of sodium and potassium excretion with blood pressure, which was most pronounced among persons consuming high-sodium diets, persons with hypertension, and older persons.

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APPENDIX

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