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Abstract

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Reference

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ORIGINAL ARTICLE

Global Sodium Consumption and Death from Cardiovascular Causes

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ABSTRACT

BACKGROUND

High sodium intake increases blood pressure, a risk factor for cardiovascular disease, but the effects of sodium intake on global cardiovascular mortality are uncertain.

METHODS

We collected data from surveys on sodium intake as determined by urinary excretion and diet in persons from 66 countries (accounting for 74.1% of adults throughout the world), and we used these data to quantify the global consumption of sodium according to age, sex, and country. The effects of sodium on blood pressure, according to age, race, and the presence or absence of hypertension, were calculated from data in a new meta-analysis of 107 randomized interventions, and the effects of blood pressure on cardiovascular mortality, according to age, were calculated from a meta-analysis of cohorts. Cause-specific mortality was derived from the Global Burden of Disease Study 2010. Using comparative risk assessment, we estimated the cardiovascular effects of current sodium intake, as compared with a reference intake of 2.0 g of sodium per day, according to age, sex, and country.

RESULTS

In 2010, the estimated mean level of global sodium consumption was 3.95 g per day, and regional mean levels ranged from 2.18 to 5.51 g per day. Globally, 1.65 million annual deaths from cardiovascular causes (95% uncertainty interval [confidence interval], 1.10 million to 2.22 million) were attributed to sodium intake above the reference level; 61.9% of these deaths occurred in men and 38.1% occurred in women. These deaths accounted for nearly 1 of every 10 deaths from cardiovascular causes (9.5%). Four of every 5 deaths (84.3%) occurred in low- and middle-income countries, and 2 of every 5 deaths (40.4%) were premature (before 70 years of age). The rate of death from cardiovascular causes associated with sodium intake above the reference level was highest in the country of Georgia and lowest in Kenya.

CONCLUSIONS

In this modeling study, 1.65 million deaths from cardiovascular causes that occurred in 2010 were attributed to sodium consumption above a reference level of 2.0 g per day. (Funded by the Bill and Melinda Gates Foundation.)

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A high dietary intake of sodium is associated with elevated blood pressure, a major risk factor for cardiovascular disease.[1,2] The United Nations,[3] World Health Organization,[4] Centers for Disease Control and Prevention, and other organizations have emphasized the relationship between dietary sodium and cardiovascular outcomes.[3-7] Yet the global effects of sodium consumption and the heterogeneity of these effects according to age, sex, and country have not been clearly established. Rates of sodium-associated cardiovascular disease have been estimated for only selected countries,[8-14] and these rates are often based on self-reported diet, without estimates of salt intake, or without considering heterogeneity due to age, race, or the presence or absence of hypertension.

As part of the Global Burden of Diseases Nutrition and Chronic Diseases Expert Group (NUTRICODE), we systematically identified and analyzed data on sodium consumption worldwide and calculated the dose–response effects of sodium on blood pressure in a new meta-analysis of trials. We also compiled data to calculate the effects of blood pressure on cause-specific cardiovascular mortality and to characterize current blood-pressure levels and numbers of cause-specific deaths according to country, age, and sex. Finally, we used data relating levels of sodium intake to blood pressure and cardiovascular events, as well as data on the lowest current levels of sodium intake according to country, to define a reference range for sodium consumption. Using all these data (Table S1 in the Supplementary Appendix, available with the full text of this article at NEJM.org), we modeled the estimated impact of current levels of sodium intake on cardiovascular mortality throughout the world.

Methods

Assessment of Global Sodium Consumption

Between March 2008 and December 2011, we performed systematic searches for previously conducted national or subnational surveys on individual-level sodium consumption based on urinary excretion, estimated dietary intake, or both.[15,16] We identified and retrieved data, according to age and sex, from published reports or direct contacts for 205 surveys: 142 surveys with data from 24-hour urine collections and 91 with estimates of dietary intake, including 28 with both types of data (Table S2 in the Supplementary Appendix). These surveys included data from 66 countries, accounting for 74.1% of adults in the world. Using a hierarchical Bayesian model, we estimated the mean level of sodium consumption and statistical uncertainty according to age, sex, and calendar year in 187 nations. An article with detailed results of these analyses has been published previously.[16]

Our model estimated sodium consumption with the use of 24-hour urine collections as the reference standard. To make our data comparable to data from prior regional surveys and blood-pressure trials in which urinary sodium levels were measured, we did not adjust our analyses for sodium loss due to factors other than urinary excretion (e.g., sweat).

The funder of this study had no role in its design or conduct; in the collection, management, analysis, or interpretation of the data; or in the preparation, review, approval, or submission of the manuscript.

Effects of Reduced Sodium Intake on Blood Pressure

Two recent Cochrane meta-analyses evaluated randomized trials of the effect of reduced sodium intake on blood pressure.[1,2] One meta-analysis was based on the results of 28 trials published through 2005.[1] The other was based on the results of 167 studies and included more recent trials, as well as trials involving low reductions in sodium intake (<0.46 g [20 mmol] per day) or brief interventions (duration of <1 week), which were excluded from the first meta-analysis.[2] These meta-analyses did not determine whether blood-pressure lowering was linear across a range of reduced sodium intakes and did not simultaneously quantify heterogeneity according to age, race, and the presence or absence of hypertension.

We performed a new meta-analysis evaluating all randomized interventions identified in these articles[1,2] (details are provided in Section S1 in the Supplementary Appendix). Using data from these trials, we evaluated whether the effects of reduced sodium intake on blood pressure were linear. We evaluated the potential heterogeneity in this effect by taking into account population characteristics, including age, the presence or absence of hypertension, and race, as well as the duration of the intervention. We also assessed whether, apart from the presence or absence of hypertension, the effects of reduced sodium in-

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take on blood-pressure lowering were blunted by the use of antihypertensive medication.

EFFECTS OF BLOOD-PRESSURE LEVELS ON CARDIOVASCULAR MORTALITY

To calculate the effects of systolic blood pressure on deaths from cardiovascular causes, we combined results from two large international projects (totaling 99 cohorts, 1.38 million participants, and 65,000 cardiovascular events) that pooled individual-level data, consistently adjusted for confounding. We accounted for regression dilution bias based on serial blood-pressure measures over time.[17,18] We interpolated and extrapolated age-specific proportional effects (relative risks) of systolic blood pressure on cardiovascular mortality in 10-year age groups across the pooling projects (see Section S2 and Fig. S3 in the Supplementary Appendix).[19] We used the same estimates of relative risk according to sex and race, on the basis of evidence of generally similar proportional effects of blood pressure on cardiovascular events according to sex and race in trials of antihypertensive drugs and observational studies of blood pressure and cardiovascular events.[19]

REFERENCE LEVELS OF SODIUM CONSUMPTION

To define reference levels of sodium consumption, we conducted a search of published survey data, cohort studies, controlled trials, and dietary recommendations, as previously reported.[15] We determined levels of sodium consumption that were associated with the lowest blood-pressure levels in ecologic studies and in randomized trials and with the lowest risk of disease in meta-analyses of prospective cohort studies. We also considered at least theoretical feasibility based on the lowest national mean levels of consumption globally. Finally, we considered the consistency of our identified reference intake levels with major dietary guidelines. Details are provided in Section S4 in the Supplementary Appendix.

CURRENT BLOOD-PRESSURE LEVELS AND CAUSE-SPECIFIC MORTALITY

Data on current blood-pressure levels and cardiovascular mortality, each according to country, age, and sex, were compiled as part of the Global Burden of Disease Study 2010.[20,21] Data on blood pressure (from 786 country-years and 5.4 million participants) were obtained from published and unpublished health examination surveys and epidemiologic studies from around the world. Data on causes of death were obtained for 187 countries from 1980 through 2010; these data were obtained from vital-registration systems, verbal autopsies, mortality surveillance, census data, surveys, hospitals, police records, and mortuaries. Details of data collection and the statistical modeling used to estimate mean systolic blood pressure and cause-specific mortality are provided in Table S1 and Sections S5 and S6 in the Supplementary Appendix.

CARDIOVASCULAR MORTALITY ASSOCIATED WITH SODIUM CONSUMPTION ABOVE THE REFERENCE LEVEL

We estimated disease burdens using comparative risk assessment,[22] capturing geographic and demographic variations in sodium intake, blood pressure, cardiovascular mortality, and corresponding uncertainties (details are provided in Table S1 and Section S7 in the Supplementary Appendix). We incorporated age-specific and sex-specific sodium intake, blood-pressure level, relative risk, and mortality data for each country to model the fraction and numbers of deaths estimated to be attributable to sodium intake above the reference level.

The population-attributable fraction was estimated in a two-step process. First, we used the effects of sodium consumption on blood pressure according to age, the presence or absence of hypertension, and race to calculate the change in mean systolic blood pressure that would be expected from reducing sodium consumption to reference levels as defined above. Second, we used the age-specific effects of blood pressure on cardiovascular mortality to calculate the resulting change in risk. Estimated numbers of deaths attributable to sodium intake above the reference level were calculated by multiplying the population-attributable fraction by the absolute number of deaths in each country, age, and sex stratum.

STATISTICAL ANALYSIS

Analyses were performed with the use of R statistical software, version 2.15.0.

RESULTS

GLOBAL SODIUM CONSUMPTION

We estimated that in 2010, the mean level of consumption of sodium worldwide was 3.95 g per day, and regional means ranged from 2.18 to 5.51 g

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per day (Fig. S1 in the Supplementary Appendix).[16] Overall, 181 of 187 countries — 99.2% of the adult population in the world — had estimated mean levels of sodium intake exceeding the World Health Organization recommendation of 2.0 g per day, and 119 countries — 88.3% of the adult population in the world — exceeded this recommended level by more than 1.0 g per day.

EFFECTS OF REDUCED SODIUM INTAKE ON BLOOD PRESSURE

In our primary analysis of reduced sodium intake and blood pressure, we found strong evidence of a linear dose–response relationship ($P<0.001$ for linearity and $P=0.58$ for nonlinearity) (Fig. 1A). When the data were evaluated with the use of inverse-variance weighted meta-regression, each reduction of 2.30 g of sodium per day was associated with a reduction of 3.82 mm Hg (95% confidence interval [CI], 3.08 to 4.55) in blood pressure (Fig. 1B).

The effects of dietary sodium on blood pressure were modified according to population characteristics, with larger reductions in blood pressure among older persons than among younger persons (Fig. S2 in the Supplementary Appendix), among blacks than among whites, and among hypertensive persons than among normotensive persons. For a white, normotensive population at 50 years of age, each reduction of 2.30 g per day in sodium intake lowered systolic blood pressure by 3.74 mm Hg (95% CI, 2.29 to 5.18). We did not find evidence of substantial blunting of the blood-pressure–lowering effects of sodium restriction by antihypertensive drugs, although the data available to address this question were limited. Further details are provided in Section S1 in the Supplementary Appendix.

EFFECTS OF BLOOD PRESSURE ON CARDIOVASCULAR MORTALITY

The pooled analyses of blood pressure and cardiovascular mortality showed a log-linear (proportional) dose–response relationship, with no evidence of a threshold as low as a systolic blood pressure of at least 115 mm Hg (see Section S2 and Fig. S3 in the Supplementary Appendix).[19] The relative magnitude of the effect on blood pressure decreased with age, in a manner similar to that seen with other cardiovascular risk factors.[19]

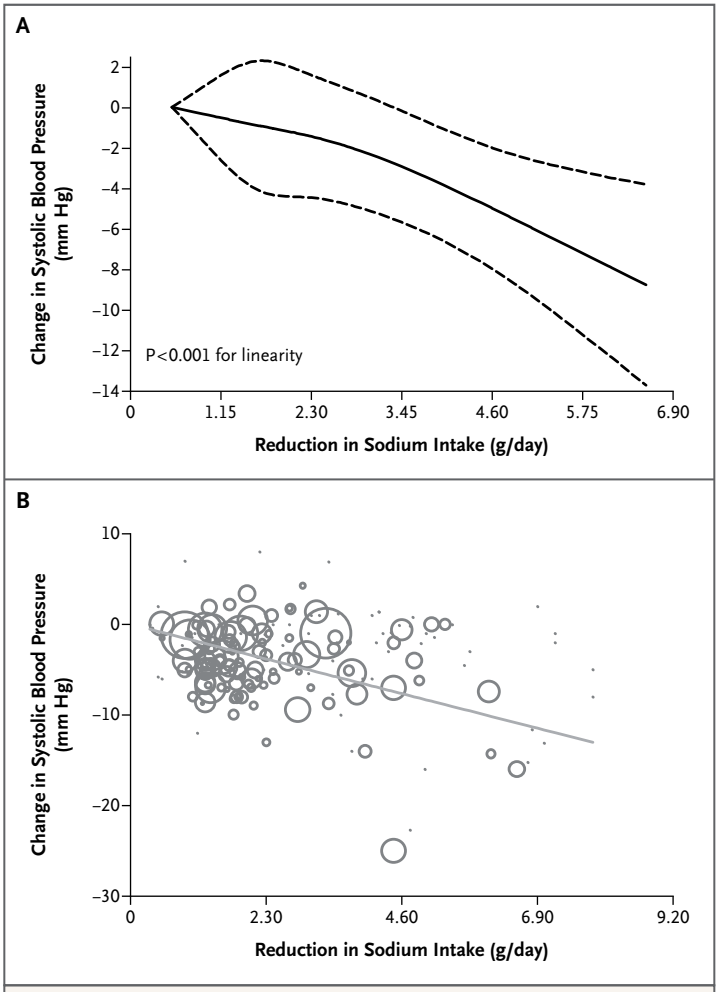


Figure 1. Effects of Reduced Sodium Intake on Systolic Blood Pressure.

Data are from 103 trials and include 107 comparison interventions (6970 persons). Reductions in sodium intake ranged from 0.53 to 6.56 g (23 to 285 mmol) per day (mean±SD, 2.28±1.27), the duration of the intervention ranged from 7 to 1100 days (mean±SD, 65±160), and the age of the participants ranged from 13 to 73 years (mean±SD, 47.4±14.4). As shown in Panel A, the effect of reduced sodium intake on systolic blood pressure was linear ($P<0.001$ for linearity), and there was little evidence of nonlinearity ($P=0.58$ for nonlinearity). The solid line represents the central estimate, and the dotted lines the 95% confidence intervals [CIs]. The model is based on inverse-variance–weighted, restricted-cubic-spline regression adjusted for age, race, and the presence or absence of hypertension. As shown in Panel B, this relationship was further examined with the use of inverse-variance–weighted linear meta-regression. Each circle represents one randomized comparison of the intervention with the control group in each trial, and the size of the circle corresponds to its inverse-variance weight. The fitted line represents the effect of reduced sodium intake across all trials (i.e., the effect according to the meta-analysis). Each reduction in sodium intake of 2.30 g (100 mmol) per day was associated with a reduction of 3.82 mm Hg (95% CI, 3.08 to 4.55) in systolic blood pressure.

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REFERENCE LEVELS OF SODIUM CONSUMPTION

Potential reference levels of sodium consumption according to various definitions are shown in Table S3 in the Supplementary Appendix. The lowest mean intake associated with both lower systolic blood pressure and a lower positive relationship between higher age and blood pressure in ecologic studies was 614 mg of sodium per day.[23] In large, well-controlled, randomized feeding trials, the lowest tested sodium intake for which reductions in blood-pressure levels were clearly documented was 1500 mg per day.[24] In prospective observational studies, the lowest mean sodium intake associated with a lower risk of cardiovascular events ranged from 1787 to 2391 mg per day.[25] We also considered observed mean levels of sodium intake that have been associated with the lowest risk of stomach cancer (1245 mg per day).[26] Levels of sodium intake associated with the lowest risk ranged from 614 to 2391 mg per day, depending on the type of evidence and the outcome. According to national data on sodium consumption,[16] the estimated lowest observed mean national intake level was approximately 1500 mg per day. The maximum level of sodium intake recommended in major dietary guidelines ranged from 1200 to 2400 mg per day.[4,7,27-30]

To estimate cardiovascular mortality attributable to sodium consumption, we used a reference level corresponding to a population mean (±SD) intake of 2.0±0.2 g of sodium per day. In sensitivity analyses, we evaluated a lower reference intake level, 1.0±0.1 g per day. We also estimated cardiovascular mortality attributable to sodium consumption above a reference intake level of 4.0±0.4 g per day, which is approximately the current mean global intake level.

ESTIMATED CARDIOVASCULAR MORTALITY ATTRIBUTED TO SODIUM CONSUMPTION

On the basis of the correlations between sodium intake and blood pressure and between blood pressure and cardiovascular mortality that are described above, and using a reference level of sodium intake of 2.0±0.2 g per day, we found that 1.65 million deaths from cardiovascular causes (95% uncertainty interval, 1.10 million to 2.22 million) worldwide in 2010 were attributable to sodium consumption above the reference level (Table 1, and Table S4 in the Supplementary Appendix). Of these deaths, 687,000 (41.7%) were due to coronary heart disease, 685,000 (41.6%) were due to stroke, and 276,000 (16.7%) were due to other cardiovascular disease. Globally, 40.4% of these deaths occurred prematurely (i.e., in persons younger than 70 years of age) (see Section S8 and Fig. S4 in the Supplementary Appendix). Four of every 5 sodium-associated deaths from cardiovascular causes (84.3%) occurred in low-income and middle-income countries. In sum, approximately 1 of every 10 deaths from cardiovascular causes worldwide (9.5%) (95% uncertainty interval, 6.4 to 12.8) and nearly 1 of every 5 (17.8%) premature deaths from cardiovascular causes were attributed to sodium consumption above the reference level.

Across nine regions of the world, the absolute rate of sodium-associated deaths from cardiovascular causes was highest in Central Asia and Eastern and Central Europe (Fig. 2A, and Fig. S5 and Table S4 in the Supplementary Appendix). Proportional cardiovascular mortality was high in all regions: among younger adults, it exceeded 10% in nearly all regions and it exceeded 20% in Central Asia and Eastern and Central Europe, East Asia, and Southeast Asia (Fig. 2B). Among older adults, who have a higher absolute risk and more competing risk factors, proportional sodium-associated cardiovascular mortality approached or exceeded 10% in Central Asia and Eastern and Central Europe, East Asia, and Southeast Asia. Most sodium-associated cardiovascular deaths were due to coronary heart disease, except in East Asia, Southeast Asia, and sub-Saharan Africa, where most deaths from cardiovascular causes were due to stroke, especially hemorrhagic and other nonischemic strokes (Table S4 and Fig. S5 in the Supplementary Appendix).

Across individual nations, substantial variation was evident. Sodium-associated cardiovascular mortality was highest in the country of Georgia (1967 deaths per 1 million adults per year; 95% uncertainty interval, 1321 to 2647) and lowest in Kenya (4 deaths per 1 million adults per year; 95% uncertainty interval, 3 to 6) (Fig. 3). Proportional cardiovascular mortality ranged from 27.4% in Mauritius (95% uncertainty interval, 18.8 to 35.9) to 0.3% in Kenya (95% uncertainty interval, 0.2 to 0.4) (Fig. 4). Among the 30 most populous nations (Fig. S6 in the Supplementary Appendix), the highest sodium-associated cardiovascular mortality was in Ukraine (1540 deaths per 1 million adults per

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Table 1. Worldwide Deaths from Cardiovascular Causes Attributed to Sodium Consumption of More than 2.0 g per Day in Adults 20 Years of Age or Older in 2010.

Variable	No. of Adults	Mean Sodium Intake (95% UI)	Mean Systolic Blood Pressure (95% UI)	Deaths Attributed to Sodium Consumption (95% UI)*				Deaths from CVD Attributed to Sodium Consumption (95% UI)†
				Coronary Heart Disease	Stroke	Other CVD	All CVDs	
	no. in millions	*g/day*	*mm Hg*	*no. in thousands*				%
Worldwide	3830	3.95 (3.89–4.01)	134 (125–144)	687 (439–963)	685 (455–927)	276 (188–365)	1648 (1095–2223)	9.5 (6.4–12.8)
Sex								
Female	1930	3.77 (3.69–3.85)	133 (123–143)	246 (151–353)	265 (174–363)	117 (79–155)	628 (410–853)	8.0 (5.4–10.9)
Male	1890	4.14 (4.04–4.23)	135 (126–145)	441 (287–610)	420 (281–564)	159 (109–209)	1020 (685–1370)	10.9 (7.4–14.7)
Age								
<70 yr	3300	3.97 (3.94–4.00)	126 (118–133)	277 (190–363)	280 (196–363)	107 (74–139)	665 (459–865)	17.8 (12.3–23.1)
≥70 yr	524	4.07 (4.04–4.10)	143 (131–155)	410 (271–557)	404 (269–547)	169 (115–223)	983 (655–1327)	8.5 (5.7–11.4)
Income level of country								
High‡	763	3.88 (3.29–4.47)	134 (125–143)	130 (87–178)	73 (49–99)	54 (37–71)	258 (172–348)	7.3 (4.9–9.8)
Upper-middle	1530	3.59 (2.86–4.31)	136 (126–146)	311 (211–415)	405 (276–539)	125 (87–163)	842 (574–1117)	12.9 (8.9–17.1)
Lower-middle	1210	3.38 (2.61–4.14)	135 (125–145)	221 (147–301)	169 (114–224)	80 (54–106)	470 (314–631)	10.6 (7.1–14.1)
Low	323	2.91 (2.22–3.60)	138 (127–149)	25 (17–33)	36 (25–47)	17 (12–22)	78 (54–102)	9.1 (6.3–11.8)

* The numbers of deaths for each subtype may not sum to the total number of deaths from cardiovascular disease because of rounding. CVD denotes cardiovascular disease, and UI uncertainty (confidence) interval.

† In 2010, there were 14,669,000 total deaths from cardiovascular disease, 6,963,000 deaths from coronary heart disease, 5,798,000 deaths from stroke, and 1,909,000 other deaths from cardiovascular disease worldwide. The values shown are the percentages of these deaths attributed to sodium consumption above the reference level of 2.0 g per day.

‡ Income categorizations are based on the World Bank classification system (http://data.worldbank.org/about/country-classifications/country-and-lending-groups).

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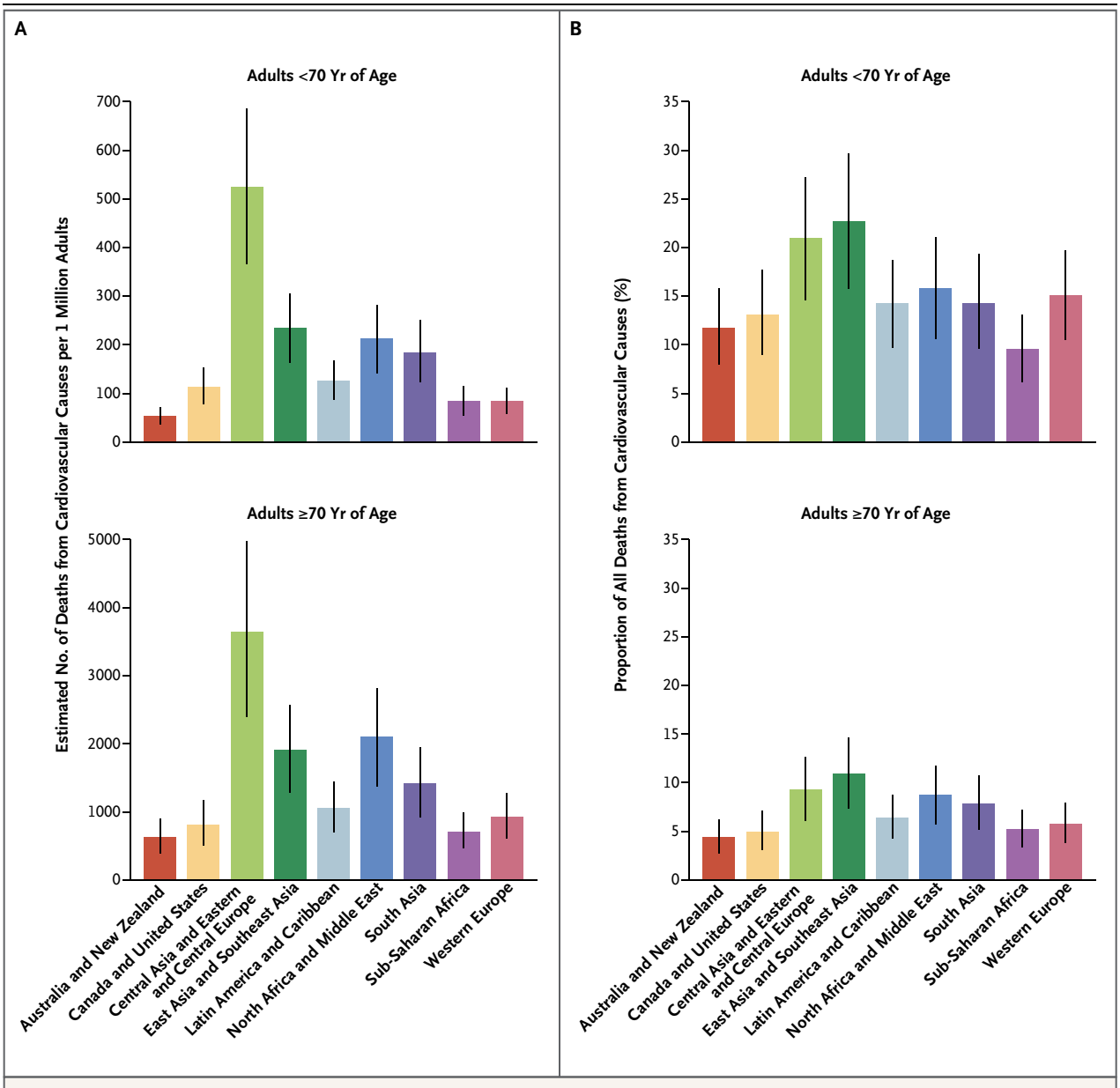


Figure 2. Cardiovascular Mortality Attributed to Sodium Consumption of More than 2.0 g per Day in 2010, According to Age and Region.

For a complete listing of countries included in each region, see Table S4 in the Supplementary Appendix. Panel A shows the absolute cardiovascular mortality (number of deaths per 1 million adults per year) attributed to sodium consumption above 2.0 g per day. Panel B shows the proportional cardiovascular mortality (the percentage of all deaths from cardiovascular causes) attributed to sodium consumption above 2.0 g per day. Vertical lines represent 95% uncertainty (confidence) intervals.

year; 95% uncertainty interval, 1017 to 2099), and the highest proportional mortality was in China (15.3% of all cardiovascular deaths; 95% uncertainty interval, 10.5 to 20.2). Detailed information about individual nations is provided in Section S9 and Table S5 in the Supplementary Appendix.

In sensitivity analyses, lowering the definition of the reference intake level from 2.0 to 1.0 g of sodium per day increased the number of deaths from cardiovascular causes in the world that were attributed to sodium consumption by approximately 40%, to 2.30 million (95% uncertainty interval, 1.55 million to 3.07 million) (Tables S6

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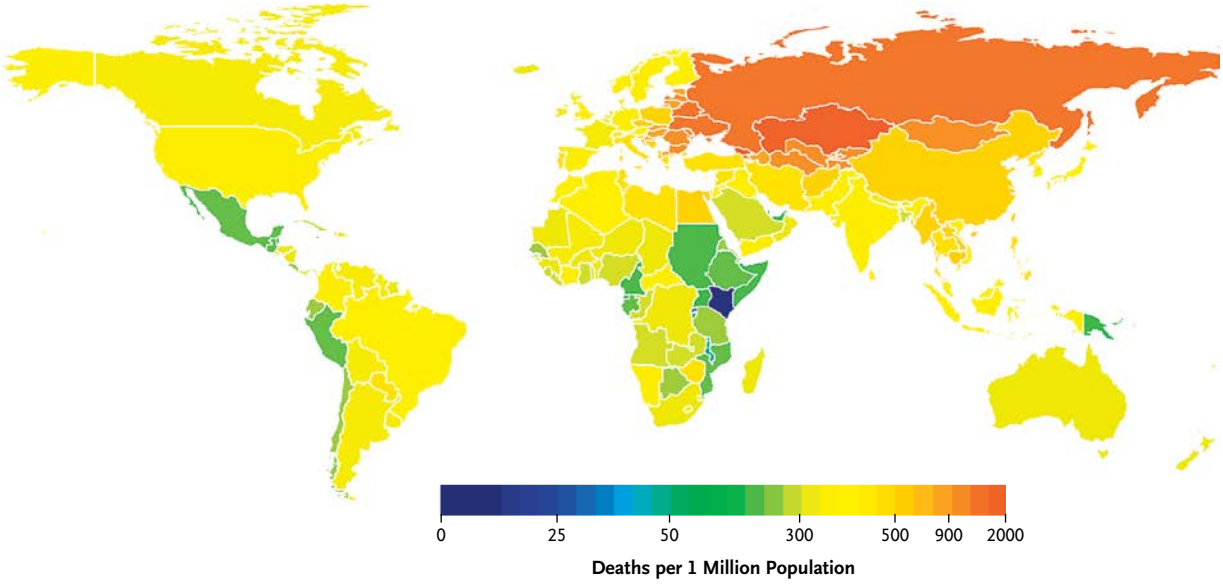


Figure 3. Absolute Cardiovascular Mortality Attributed to Sodium Consumption of More than 2.0 g per Day in 2010, According to Nation.
The scale is based on the number of deaths from cardiovascular causes (per 1 million persons) in 2010 that were attributed to sodium consumption of more than 2.0 g per day.

and S7 and Fig. S7 and S8 in the Supplementary Appendix). When we estimated effects attributable only to sodium intake above 4.0±0.4 g per day, 512,901 worldwide deaths from cardiovascular causes (95% uncertainty interval, 333,710 to 704,773) were attributed to such consumption (Tables S8 and S9 in the Supplementary Appendix). This was the estimated number of deaths that were potentially preventable if only the nations with the highest level of sodium consumption lowered their intake to just the current mean intake in the world. If we altered our model so that the estimated benefits of blood-pressure lowering did not continue below 125 mm Hg, 1.55 million deaths from cardiovascular causes in the world (95% uncertainty interval, 1.10 million to 2.10 million) were attributed to sodium consumption above a level of 2.0 g per day.

DISCUSSION

We used currently available data on sodium consumption, dose–response effects on blood pressure and on cardiovascular mortality, and cause-specific deaths to estimate the effect of current sodium intake on cardiovascular mortality worldwide. Globally, 1.65 million deaths from cardiovascular causes in 2010 — about 1 of 10 deaths from cardiovascular causes — were attributed to sodium consumption of more than 2.0 g per day. Notably, 4 of 5 of these deaths occurred in low- and middle-income countries, and 2 of 5 of these deaths occurred prematurely (before the age of 70 years).

Our findings also show and quantify the heterogeneity in disease burden attributed to sodium according to region, age, and type of cardiovascular disease. Yet, we also found that no region and few countries were spared. Whereas estimated sodium-associated cardiovascular mortality was highest in Central Asia, it was high (more than 750 deaths per 1 million adults who were 70 years of age or older) in all regions. The estimated number of proportional sodium-associated deaths was also high, approaching or exceeding 15% of premature deaths from cardiovascular causes in most regions.

Our meta-analysis of 107 randomized interventions in 103 trials showed a linear dose–response relationship between reduced sodium intake and blood pressure, jointly modified according to age, race, and the presence or absence of hypertension. These findings are consistent with the findings of a meta-analysis, published after submission

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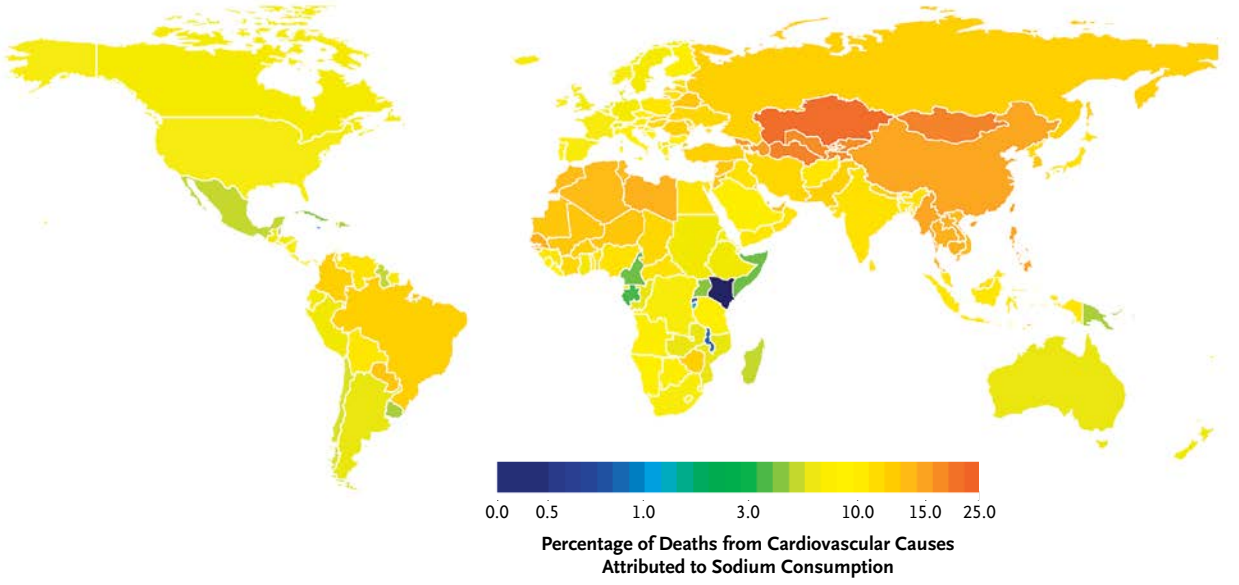


Figure 4. Proportion of Deaths from Cardiovascular Disease Attributed to Sodium Consumption of More than 2.0 g per Day in 2010, According to Nation.

The scale is based on the percentage of all deaths from cardiovascular causes in 2010 that were attributed to sodium consumption of more than 2.0 g per day.

of this article, that included fewer trials (34 trials).[31] Larger effects in older adults and hypertensive persons would be consistent with decreasing vascular compliance and renal filtration; in blacks, larger effects would be consistent with differences in renal handling of sodium.[32-34] We used randomized trials of reduced sodium intake and blood pressure to estimate the more conceptually appropriate effect of lifetime differences in intake, because direct evidence on lifetime effects, which may be larger, is available only from ecologic comparisons and experiments involving nonhuman primates.[35]

Some researchers have argued that it may not be possible to directly extrapolate the effects of sodium on blood pressure to cardiovascular risk. However, the effect on cardiovascular disease is supported by extensive experimental and ecologic evidence, data on cardiovascular events from some trials of reduced sodium intake, and evidence of the cardiovascular benefits of blood-pressure lowering across multiple interventions (see Section S3 in the Supplementary Appendix).[5,7,36,37] A meta-analysis of prospective cohort studies showed that higher sodium consumption was associated with a higher rate of death from coronary heart disease (relative risk, 1.32; 95% CI, 1.13 to 1.53) and death from stroke (relative risk, 1.63; 95% CI, 1.27 to 2.10), the two main end points in our analysis.[25] Although concerns have been raised that reduced sodium intake may cause physiological harm, a meta-analysis of 37 trials showed no significant adverse effects on blood lipid levels, catecholamine levels, or renal function.[25]

There is mixed evidence from observational data on the relationship between very low sodium intake and cardiovascular events. A recent Institute of Medicine report concluded that, if restricted to studies of clinical cardiovascular events, there is insufficient evidence that lowering sodium intake further beyond 2.30 g per day either increases or decreases the occurrence of cardiovascular disease.[38] Yet the report further concluded that the entirety of the evidence, "when considered collectively, indicates a positive relationship between higher levels of sodium intake and [the] risk of cardiovascular disease."[38] Although precise targets for sodium reduction remain controversial, various organizations tasked with reviewing all the evidence have arrived at target levels ranging from 1200 to 2400 mg per day (Table S3 in the Supplementary Appendix).

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The potential limitations of our study should be considered. Although we made every effort to maximize validity, minimize error and bias, and incorporate heterogeneity and uncertainty, our modeling cannot prove that sodium restriction reduces cardiovascular mortality. Our primary metric for estimating dietary sodium was based on 24-hour urine collections, which reflect approximately 90% of intake and also can be limited by incomplete collection. Data on sodium intake were not available across all countries or years; this increased statistical uncertainty and the risk that some data could reflect sampling bias. We focused on cardiovascular mortality, but dietary sodium is also associated with nonfatal cardiovascular disease, kidney disease, and gastric cancer,[26] the second-leading fatal cancer worldwide.[21] Consequently, our findings may underestimate the full global health effects of dietary sodium. We did not have data on potassium consumption, which also influences blood pressure and the risk of stroke.[39,40] Our model did not incorporate specific approaches or timelines for reduced sodium intake, which could be informed by other efforts.[41-43]

In conclusion, we carried out a study to model the estimated effect of sodium consumption on cardiovascular mortality. On the basis of currently available data on sodium consumption, dose–response effects on blood pressure and cardiovascular mortality, and cause-specific deaths, we estimate that in 2010, a total of 1.65 million deaths from cardiovascular causes were attributable to consumption of more than 2.0 g of sodium per day.

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