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Health and Budgetary Impact of Achieving 10-Year U.S. Sodium Reduction Targets

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Abstract

Introduction: This study estimates the health, economic, and budgetary impact resulting from graduated sodium reductions in the commercially produced food supply of the U.S., which are consistent with draft U.S. Food and Drug Administration voluntary guidance and correspond to Healthy People 2020 objectives and the 2015–2020 Dietary Guidelines for Americans.

Methods: Reduction in mean U.S. dietary sodium consumption to 2,300 mg/day was implemented in a microsimulation model designed to evaluate prospective cardiovascular disease–related policies in the U.S. population. The analysis was conducted in 2018–2020, and the microsimulation model was constructed using various data sources from 1948 to 2018. Modeled outcomes over 10 years included prevalence of systolic blood pressure ≥140 mmHg; incident myocardial infarction, stroke, cardiovascular disease events, and cardiovascular disease–related mortality; averted medical costs by payer in 2017 U.S. dollars; and productivity.

Results: Reducing sodium consumption is expected to reduce the number of people with systolic blood pressure ≥140 mmHg by about 22% and prevent approximately 895.2 thousand cardiovascular disease events (including 218.9 thousand myocardial infarctions and 284.5 thousand strokes) and 252.5 thousand cardiovascular disease–related deaths over 10 years in the U.S. Savings from averted disease costs are expected to total almost $37 billion—most of which would be attributed to Medicare ($18.4 billion) and private insurers ($13.4 billion)—and increased productivity from reduced disease burden and premature mortality would account for another $18.2 billion in gains.

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SUPPLEMENTAL MATERIAL

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Conclusions: Systemic sodium reductions in the U.S. food supply can be expected to produce substantial health and economic benefits over a 10-year period, particularly for Medicare and private insurers.

INTRODUCTION

One third of U.S. adults have hypertension (using a diagnostic blood pressure [BP] threshold of ≥140/90 mmHg); among whom, around half do not have it controlled.[1,2] Excess dietary sodium consumption is known to contribute to developing and limiting the control of hypertension and is potentially amenable to public health interventions.[3,4] Therefore, organizations including HHS,[5] American Heart Association,[6] and WHO[7] have called for reductions in dietary sodium intake, but the estimates of the corresponding population health benefits have varied.[8–13]

Mean daily sodium intake among U.S. adults currently exceeds 3,500 mg/day[14]—well above recommended levels.[15,16] The solution is not as simple as withholding the salt shaker. More than 70% of dietary sodium in the U.S. is estimated to come from salt added during commercial processing and preparation of packaged and restaurant foods.[17] Sodium labeling for packaged foods and awareness of reduction tactics have not been sufficient for most adults attempting to lower intake.[18] Therefore, with a stated goal of helping Americans reduce their sodium consumption to ≤2,300 mg/day as recommended by Healthy People 2020 and the 2015–2020 Dietary Guidelines for Americans,[15,16] the U.S. Food and Drug Administration (FDA) published draft guidance for the food industry in 2016 to achieve a 10-year gradual and voluntary reduction of sodium in commercially packaged and prepared foods.[19,20]

Voluntary sodium reduction policies have been effective at reducing sodium intake in other countries,[21–23] and epidemiologic data suggest concurrent health benefits.[24–26] Several modeling studies based on the U.S. population also predict considerable benefits from lowering sodium consumption,[8–13] but among those identified studies, only 1 provided primary analyses consistent with the FDA draft guidance,[13] and none estimated how U.S. population sodium reduction would reduce downstream medical costs for major payer groups, specifically, Medicare, Medicaid, and private insurers. In addition, most of the studies did not account for important age-, sex-, or race-based differences in sodium consumption or sodium's effect on BP. The objective of this study was to bridge these gaps using microsimulation modeling to estimate the potential health effects and the associated budgetary impacts of averted disease costs by major payer groups over a 10-year period if mean sodium consumption among U.S. adults could be reduced to 2,300 mg/day.

METHODS

Model Design and Analytical Approach

Analyses were conducted in 2018–2020 using the HealthPartners Institute's ModelHealth™: Cardiovascular disease (CVD) microsimulation model, which incorporates data collected in 1948–2018. ModelHealth: CVD is an annual-cycle microsimulation model designed to estimate the long-term incidence of CVD events and associated costs in a cross section of

individuals representative of the U.S. population. Details of this model have been described elsewhere,[27–29] and a comprehensive description of modeled population and the model structure are provided in Appendices A and B (available online).

In brief, risk equations that determine disease outcomes in the model were derived from the Framingham Heart Study data.[30,31] Event risk is based on a person's age, sex, BMI, systolic BP (SBP), cholesterol levels, smoking status, diabetes status, and CVD history. Disease costs were estimated from the Medical Expenditure Panel Survey.[32] Initial health insurance status was derived from Current Population Survey data,[33] and year-to-year transitions in primary payer type were derived from Survey of Income and Program Participation data.[34] Productivity measures capture lost market and household productivity owing to CVD-related premature death, absenteeism, and presenteeism (i.e., less productive at work owing to poor health).[35,36] All monetary measures are presented in 2017 U.S. dollars.

All analyses compared outcomes over a 10-year period for a simulated population exposed to a national sodium reduction policy to the same population without exposure to this policy, everything else held equal. The policy affects outcomes in the model by lowering SBP on the basis of age, sex, race, and hypertension status, as detailed herein. Modeled and reported health outcomes include prevalence of uncontrolled hypertension (SBP ≥140 mmHg) and incident myocardial infarction (MI), stroke, CVD events (MI, stroke, congestive heart failure hospitalization, angina onset, and intermittent claudication onset), and CVD-related mortality. Reported economic outcomes include averted medical costs by payer and productivity gains. Food reformulation and other policy costs associated with achieving and maintaining the voluntary FDA sodium targets were not included in this study because these costs will not be borne by health insurance plans. Alternative parameter assumptions were assessed with sensitivity analysis. Results are representative of and scaled to the U.S. population aged ≥35 years on the basis of a simulated sample of 1 million people, including those aged 25–34 years who age into the cross section over the 10-year period. Initial demographic characteristics for the modeled population are presented in Appendix Table A1 (available online).

Policy Design and Effects

The draft FDA voluntary guidance provides targets to support a gradual reduction in sodium in packaged and prepared foods over 2 and 10 years.[19,20] The modeled policy aligns with this approach and achieves a population average sodium consumption of 2,300 mg/day among adults aged ≥30 years over a 10-year period. One third of the reduction is achieved in the first 2 years, and the remaining two-thirds reduction is achieved in the remaining 8 years.

Sodium consumption varies primarily by age and sex, and baseline estimates for current mean daily sodium intake are based on U.S. dietary data from 2015 to 2016.[14] A large meta-analysis by Mozaffarian et al.,[37] which found sodium's effect on BP (i.e., sodium sensitivity) to be a function of age, race, and hypertension status, was used as specified in Appendix Table A2 (available online). The combined estimated effect of the draft FDA voluntary guidance on sodium consumption and SBP for population groups is summarized in Table 1 and detailed year-by-year in Appendix Tables A3 and A4 (available online). Although policy effects were modeled for people aged ≥35 years, sodium reduction targets

were calculated for those aged ≥30 years to align with how sodium consumption is reported by age.[14]

Characterizing the variability in sodium sensitivity is a challenge,[38] and previously published models have incorporated different estimates of sodium sensitivity across population subgroups.[8–13] Therefore, additional analyses were conducted using alternative estimates of sodium sensitivity among population subgroups (summary is provided in Appendix Table A2, available online).[8,10,39] In addition, effects were assessed of hypothetical scenarios in which (1) only the 2-year goals of the draft-proposed FDA guidance are achieved, (2) the 10-year goals are achieved immediately, and (3) each person reduces their sodium consumption to ≤2,300 mg/day.

RESULTS

The baseline mean daily sodium intake among all adults aged ≥30 years was 3,488 mg/day —4,048 mg/day among men and 2,977 mg/day among women (Table 1). To achieve a mean daily sodium intake of 2,300 mg/day in 10 years would require a 34.1% reduction in daily sodium intake across all age and sex subgroups, resulting in an overall reduction of 1,380 mg/day and 1,015 mg/day among men and women, respectively.

A 10-year graduated reduction in dietary sodium, as proposed by the FDA, is projected to reduce the number of Americans with SBP ≥140 mmHg by 6.9 million (22% reduction) (Table 2) and the number of Americans with SBP 120–139 mmHg by 8.1 million (13% reduction). This is as a result of a 2.4-mmHg (2%)-average reduction in SBP in the overall population. Over 10 years, the reductions in sodium consumption are estimated to prevent 895.2 thousand CVD events (including 218.9 thousand MIs and 284.5 thousand strokes) and 252.5 thousand CVD-related deaths.

These health benefits correspond with sizable estimated reductions in medical costs from averted disease—almost $36.9 billion across all payers in 10 years (Table 2). Medicare benefits the most, with $18.4 billion in averted medical costs, followed by private insurers with an estimated $13.4 billion reduction. The remaining $5.0 billion in averted medical costs are distributed among the uninsured ($3.5 billion), Medicaid enrollees ($0.9 billion), and individuals with other insurance coverage ($0.6 billion). The improved health outcomes are also predicted to generate societal productivity gains of $18.2 billion over a 10-year period through fewer lost work days and increases in workplace and household productivity and earnings.

Achieving the goal outlined in the draft-proposed FDA guidance is estimated to have differential health effects by age and sex over 10 years (Table 3) because of the inherent differences that exist in sodium consumption and risk for developing CVD by age and sex and sodium sensitivity by age.

If only the first 2 years of the dietary sodium goals (one third of the total target) are achieved with no additional reduction in the following 8 years, approximately half of the benefits in terms of prevented CVD events and averted disease costs can still be realized over a 10-year period (Table 4). This is because 10 years is sufficient to reap meaningful indirect benefits of

events that otherwise would have occurred downstream. About 50% more MIs and strokes would be prevented assuming that the sodium goals can be achieved immediately, rather than gradually over 10 years. The estimated gains for getting everyone to a daily sodium consumption level of ≤2,300 mg/day compared with the base case analysis are modest, with only about 9% more MIs and 4% more strokes prevented.

When comparing sodium sensitivity assumptions using the estimates from Bibbins-Domingo et al.[10] (low bound), Coxson et al.[8] and He et al.[39] all provide results of generally similar magnitude as the primary analysis (Table 4). However, the 10-year effects are lowest when using the pooled sodium sensitivity estimates from He et al.,[39] which assumed no elevation in sensitivity due to age or race, and highest when using the values from Bibbins-Domingo et al.[10] (high bound), which assumed both age and race differences in sodium sensitivity.

DISCUSSION

The findings presented here suggest that meaningful health benefits and averted disease costs, similar in scale to a nationwide adoption of team-based programs to manage uncontrolled hypertension,[28,40] could be achieved through a gradual reduction in dietary sodium, such as through incremental modification of sodium found in the commercially manufactured and prepared food supply. Moreover, the sensitivity analysis indicates that even partial success in achieving these goals can still result in substantive health benefits for individuals and budgetary benefits for major healthcare payers over a 10-year period.

This analysis is not a novel use of predictive modeling to estimate the health and economic impacts of sodium reduction,[8–13] but to the authors' knowledge, this is the first to estimate cost outcomes by healthcare payer. With full implementation of this sodium reduction strategy, an estimated $36.9 billion would be saved in CVD-related healthcare spending over a 10-year period. Medicare and private insurers would receive the greatest benefit—$18.4 billion and $13.4 billion, respectively—because of the total number of members they serve and for Medicare, because of their members' older age profile and greater risk for CVD events. The potential savings reaped by Medicare with implementation of this strategy would, on an annual basis, equate to the estimated savings Medicare achieved in 2016 through their national efforts to reduce hospital readmissions, which was largely driven by their Hospital Readmissions Reduction Program.[41] Other payer groups would also receive considerable benefit from these cost reductions, including the uninsured who would see a $3.5 billion reduction in their spending—savings that may also benefit hospitals who serve large numbers of uninsured patients and often remain uncompensated for the care they provide.[42] Furthermore, an additional $18.2 billion in added productivity among U.S. adults is projected over the 10-year period—which comes from people living longer, healthier, and thereby more productive lives that benefit themselves and their employers (if employed)—resulting in a total gain to the society of $55.1 billion with full implementation of this strategy.

ModelHealth: CVD has been widely used to assess prevention policies in the U.S.[27–29,40,43] and features targeting interventions on individual-level transitions in cardiometabolic risk factors and disease events to predict long-term health and economic effects. The methods

and assumptions in previous modeling analyses vary considerably, making direct comparisons with the results of this study challenging. Dall et al.[12] and Palar et al.[11] predicted 3.3–11.1 million reduction in in the number of hypertension cases and $5.5–$18 billion savings in healthcare costs annually, respectively, for policy scenarios that achieved about a 1,100 mg/day immediate reduction in the sodium consumption of the population. Smith-Spangler et al.[9] used a Markov model to estimate lifetime impacts from about a 10% reduction in sodium consumption among the current U.S. cohort aged 40–85 years, which resulted in about half a million prevented MIs and strokes each and $32.1 billion accumulated savings in medical costs. Assuming a 10-year−graduated reduction in sodium similar to this study, Bibbins-Domingo et al.[10] found averted total healthcare costs ranging from $56.9 to $96.6 billion (compared with $36.9 billion in CVD-related costs in this study). Part of this difference may be attributable to their assumption that sodium reductions were equal across age and sex groups. Coxson et al.[8] found that the smallest estimates of benefit generally result from translating reductions in sodium to reductions in BP to reductions in CVD risk, as done in this study.

The primary analysis of Pearson-Studdard et al.[13] had a design and objective most similar to this study. Their study used the same Mozaffarian et al.[37] estimates for sodium sensitivity and included a similar gradual sodium reduction scenario. However, notable differences include that Pearson-Studdard et al.[13] (1) started with a baseline median sodium intake of 3,110 mg/day (compared with a mean baseline of 3,488 mg/day in this study and about 3,400 mg/day as cited by the FDA[19]), which resulted in a net median reduction in sodium consumption of 750 mg/day (compared with a mean reduction of 1,189 mg/day in this study); (2) estimated outcomes for U.S. adults aged 30–84 years (compared with 35–100 years in this study); (3) assumed a 5-year lag in reduced sodium consumption affecting health outcomes (compared with no lag assumed in this study); and (4) estimated outcomes over a 20-year horizon (compared with this study's 10-year horizon). In annualized terms, compared with this study's estimate of about 28,000 per year, Pearson-Studdard et al.[13] estimated a stroke reduction of 9,000 per year, and they also estimated a reduction in CVD deaths of 1,750 per year compared with this study's estimate of about 25,000 per year. Part of this difference can be explained by Points 1–3, but the remainder would appear to be in how each model's risk equations translate reductions in BP to event risk reduction. Meta-analysis indicates that a 1-mmHg increase in SBP may increase CVD mortality risk by 1.6%.[44] In 2016, there were about 841,000 deaths from CVD in the U.S.,[45] and in this study, an average reduction in SBP of 2.4 mmHg was estimated. These figures combined suggest a 3.8% expected reduction in CVD deaths or about 32,000 per year in the U.S., which would align more closely with estimates in this study.

Limitations

Although the model equations that translate risk factors to disease events are not race/ethnicity-specific, the risk factors themselves are race/ethnicity-specific and event prevalence estimates validate reasonably well across demographic groups (Appendix Table B31, available online). This study did not explicitly account for some potential confounders, such as physical activity level, but results account for these factors at population average levels. Only CVD-related effects of sodium reduction are accounted for; however, other

health benefits could occur, including reductions in gastric cancer.[46] Dietary sodium intake measured using dietary data is often lower than that measured using urinary excretion methods,[47–49] which would result in conservative estimates for the health benefits realized by achieving national sodium reduction goals. National clinical guidelines published in 2017 lowered the threshold for diagnosing and controlling hypertension.[50] Applying this definition would change the BP control estimates observed in this study, but it would have no effect on the disease and cost outcomes which are determined based on changes in SBP. In addition, policy effects were derived proportionally to overall sodium consumption in each population subgroup but did not account for how specific foods with greater (or lesser) sodium reductions suggested by FDA targets may be disproportionately consumed within population groups (which could lead to policy effects that are not strictly proportional to baseline sodium consumption). The effect estimates in this model are assumed to be similar for sodium reduction above and below 2,300 mg/day and to differ by factors other than hypertension status. However, direct evidence on the reduction in chronic disease risk for intakes below 2,300 mg/day is limited, and the benefits and risks of sodium restriction below the chronic disease risk reduction level (i.e., 2,300 mg for adults) are uncertain.[38] Thus, if chronic disease risk reduction is less when intake falls below 2,300 mg/day, the benefits may be overstated.

The draft FDA voluntary guidance does not include discretionary salt added by the consumer, and this analysis assumes that commercial food reformulations, applied broadly across all food categories, are sufficient to meet the population goal of average total population sodium consumption to 2,300 mg/day. If a few manufacturers choose to reduce the sodium content of their foods or consumers offset commercial reductions in sodium by salting their own food, the findings may overstate the policy's effects. However, evidence from other countries indicates that voluntary reductions can be effective in reducing population sodium intake.[23] In addition, RCTs indicate that consumers add back less sodium than the amount removed when foods are reformulated,[51,52] and evidence from the United Kingdom indicates that a consumer awareness campaign conducted alongside the reformulation of commercially produced foods to contain lower sodium levels coincides with lower discretionary use of salt by consumers.[53] If lower discretionary salt use were to occur in the U.S., this study might understate the benefits. In addition, reformulation of foods to reduce the sodium content can be achieved through substituting potassium chloride for salt. The health effects of this substitution were not modeled, potentially understating the benefits on BP.[38]

CONCLUSIONS

Much is yet to be seen regarding the cost, technological feasibility, and consumer behaviors related to significant, albeit gradual, reductions in sodium contained in commercially produced foods. Government actions should balance these considerations as much as they can be known, but this analysis suggests that systemic sodium reductions in the U.S. food supply could produce meaningful population health benefits and substantial economic value for healthcare payers, particularly Medicare and private insurers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Wall HK, Ritchey MD, Gillespie C, Omura JD, Jamal A, George MG. Vital Signs: prevalence of key cardiovascular disease risk factors for Million Hearts 2022 - United States, 2011–2016. MMWR Morb Mortal Wkly Rep. 2018;67(35):983–991. 10.15585/mmwr.mm6735a4. [PubMed: 30188885]
2. Fryar CD, Ostchega Y, Hales CM, Zhang G, Kruszon-Moran D. Hypertension prevalence and control among adults: United States, 2015–2016. NCHS Data Brief. 2017;289:1–8.
3. Jackson SL, King SM, Zhao L, Cogswell ME. Prevalence of excess sodium intake in the United States - NHANES, 2009–2012. MMWR Morb Mortal Wkly Rep. 2016;64(52):1393–1397. 10.15585/mmwr.mm6452a1. [PubMed: 26741238]
4. Strom BL, Yaktine AL, Oria M. Sodium Intake in Populations: Assessment of Evidence. Washington, DC: National Academies Press, 2013.
5. DeSalvo KB, Olson R, Casavale KO. Dietary guidelines for Americans. JAMA. 2016;315(5):457–458. 10.1001/jama.2015.18396. [PubMed: 26746707]
6. Whelton PK, Appel LJ, Sacco RL, et al. Sodium, blood pressure, and cardiovascular disease: further evidence supporting the American Heart Association sodium reduction recommendations. Circulation. 2012;126(24):2880–2889. 10.1161/CIR.0b013e318279acbf. [PubMed: 23124030]
7. WHO. Guideline: Sodium Intake for Adults and Children. Geneva, Switzerland: WHO, 2012.
8. Coxson PG, Cook NR, Joffres M, et al. Mortality benefits from U.S. population-wide reduction in sodium consumption: projections from 3 modeling approaches. Hypertension. 2013;61(3):564–570. 10.1161/HYPERTENSIONAHA.111.201293. [PubMed: 23399718]
9. Smith-Spangler CM, Juusola JL, Enns EA, Owens DK, Garber AM. Population strategies to decrease sodium intake and the burden of cardiovascular disease: a cost-effectiveness analysis. Ann Intern Med. 2010;152(8):481–487. 10.7326/0003-4819-152-8-201004200-00212. [PubMed: 20194225]
10. Bibbins-Domingo K, Chertow GM, Coxson PG, et al. Projected effect of dietary salt reductions on future cardiovascular disease. N Engl J Med. 2010;362(7):590–599. 10.1056/NEJMoa0907355. [PubMed: 20089957]
11. Palar K, Sturm R. Potential societal savings from reduced sodium consumption in the U.S. adult population. Am J Health Promot. 2009;24(1):49–57. 10.4278/ajhp.080826-QUAN-164. [PubMed: 19750962]
12. Dall TM, Fulgoni VL 3rd, Zhang Y, Reimers KJ, Packard PT, Astwood JD. Predicted national productivity implications of calorie and sodium reductions in the American diet. Am J Health Promot. 2009;23(6):423–430. 10.4278/ajhp.081010-QUAN-227. [PubMed: 19601482]
13. Pearson-Stuttard J, Kypridemos C, Collins B, et al. Estimating the health and economic effects of the proposed U.S. Food and Drug Administration voluntary sodium reformulation: microsimulation cost-effectiveness analysis. PLoS Med. 2018;15(4):e1002551 10.1371/journal.pmed.1002551. [PubMed: 29634725]
14. Agriculture Research Service. Nutrient intake from food and beverages: mean amounts consumed per individual, by gender and age What We Eat in America, NHANES 2015–2016. Beltsville, MD: U.S. Department of Agriculture, Agriculture Research Service www.ars.usda.gov/ARSUserFiles/80400530/pdf/1516/Table_1_NIN_GEN_15.pdf.. Published 2018 Accessed June 14, 2019.

15. Healthy People 2020, nutrition and weight status. HHS. www.healthy-people.gov/2020/topics-objectives/topic/nutrition-and-weight-status/objectives. Updated April 21, 2020. Accessed March 28, 2016.
16. HHS, U.S. Department of Agriculture. Dietary Guidelines for Americans 2015–2020. 8th Edition New York, NY: Simon and Schuster, 2015.
17. Harnack LJ, Cogswell ME, Shikany JM, et al. Sources of sodium in U.S. adults from 3 geographic regions. Circulation. 2017;135(19):1775–1783. 10.1161/circulationaha.116.024446. [PubMed: 28483828]
18. Patel D, Cogswell ME, John K, Creel S, Ayala C. Knowledge, attitudes, and behaviors related to sodium intake and reduction among adult consumers in the United States. Am J Health Promot. 2017;31(1):68–75. 10.4278/ajhp.150102-QUAN-650. [PubMed: 26389978]
19. Draft guidance for industry: voluntary sodium reduction goals: target mean and upper bound concentrations for sodium in commercially processed, packaged, and prepared foods for voluntary sodium reduction goals. U.S. Food and Drug Administration, 2016 www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ucm494732.htm. Accessed September 28, 2016.
20. Sodium reduction. U.S. Food and Drug Administration www.fda.gov/food/food-additives-petitions/sodium-reduction. Updated 2018. Accessed October 17, 2019.
21. Trieu K, Neal B, Hawkes C, et al. Salt reduction initiatives around the world - a systematic review of progress towards the global target. PLoS One. 2015;10(7):e0130247 10.1371/journal.pone.0130247. [PubMed: 26201031]
22. Barberio AM, Sumar N, Trieu K, et al. Population-level interventions in government jurisdictions for dietary sodium reduction: a Cochrane Review. Int J Epidemiol. 2017;46(5):1551–1405. 10.1093/ije/dyw361. [PubMed: 28204481]
23. Hyseni L, Elliot-Green A, Lloyd-Williams F, et al. Systematic review of dietary salt reduction policies: evidence for an effectiveness hierarchy. PLoS One. 2017;12(5):e0177535 10.1371/journal.pone.0177535. [PubMed: 28542317]
24. Sasaki N The salt factor in apoplexy and hypertension: epidemiological studies in Japan In: Yamori Y, Lovinberg W, Freis E, eds. Perspectives in Cardiovascular Research. New York, NY: Raven Press, 1979:467–474.
25. Karppanen H, Mervaala E. Sodium intake and hypertension. Prog Cardiovasc Dis. 2006;49(2):59–75. 10.1016/j.pcad.2006.07.001. [PubMed: 17046432]
26. He FJ, Pombo-Rodrigues S, Macgregor GA. Salt reduction in England from 2003 to 2011: its relationship to blood pressure, stroke and ischaemic heart disease mortality. BMJ Open. 2014;4(4):e004549 10.1136/bmjopen-2013-004549.
27. Dehmer SP, Maciosek MV, Flottemesch TJ, LaFrance AB, Whitlock EP. Aspirin for the primary prevention of cardiovascular disease and colorectal cancer: a decision analysis for the U.S. Preventive Services Task Force. Ann Intern Med. 2016;164(12):777–786. 10.7326/M15-2129. [PubMed: 27064573]
28. Dehmer SP, Baker-Goering MM, Maciosek MV, et al. Modeled health and economic impact of team-based care for hypertension. Am J Prev Med. 2016;50(5 suppl 1):S34–S44. 10.1016/j.amepre.2016.01.027. [PubMed: 27102856]
29. Dehmer SP, Maciosek MV, LaFrance AB, Flottemesch TJ. Health benefits and cost-effectiveness of asymptomatic screening for hypertension and high cholesterol and aspirin counseling for primary prevention. Ann Fam Med. 2017;15(1):23–36. 10.1370/afm.2015. [PubMed: 28376458]
30. Framingham Heart Study—Cohort. Calverton, MD: Biologic Specimen and Data Repository Information Coordinating Center, NIH; 2010
31. Framingham Heart Study—Offspring. Calverton, MD: Biologic Specimen and Data Repository Information Coordinating Center, NIH; 2010
32. Agency for Healthcare Research and Quality. Medical Expenditure Panel Survey; 2001–2010. http://meps.ahrq.gov/mepsweb/. Accessed March 16, 2020.
33. Current Population Survey data for social, economic and health research. IPUMS CPS. https://cps.ipums.org/cps/. Accessed March 15, 2018.

34. SIPP 2008 Panel Data. U.S. Census Bureau. www.census.gov/programs-surveys/sipp/data/2008-panel.html. Updated 2008. Accessed 2014.
35. Grosse SD, Krueger KV, Mvundura M. Economic productivity by age and sex: 2007 estimates for the United States. Med Care. 2009;47(7 suppl 1):S94–S103. 10.1097/MLR.0b013e31819c9571. [PubMed: 19536021]
36. Mitchell RJ, Bates P. Measuring health-related productivity loss. Popul Health Manag. 2011;14(2):93–98. 10.1089/pop.2010.0014. [PubMed: 21091370]
37. Mozaffarian D, Fahimi S, Singh GM, et al. Global sodium consumption and death from cardiovascular causes. N Engl J Med. 2014;371(7):624–634. 10.1056/NEJMoa1304127. [PubMed: 25119608]
38. Stallings VA, Harrison M, Oria M. Dietary Reference Intakes for Sodium and Potassium. Washington, DC: National Academies Press, 2019.
39. He FJ, Li J, Macgregor GA. Effect of longer-term modest salt reduction on blood pressure. Cochrane Database Syst Rev. 2013;(3):CD004937 10.1002/14651858.CD004937.pub2.
40. Overwyk KJ, Dehmer SP, Roy K, et al. Modeling the health and budgetary impacts of a team-based hypertension care intervention that includes pharmacists. Med Care. 2019;57(11):882–889. 10.1097/MLR.0000000000001213. [PubMed: 31567863]
41. Medicare Payment Advisory Commission. Report to the congress: Medicare and the health care delivery system. Washington, DC Medicare Payment Advisory Commission; 2018 http://medpac.gov/docs/default-source/reports/jun19_medpac_reporttocongress_sec.pdf.
42. Glied S, Kronick R. The value of health insurance: few of the uninsured have adequate resources to pay potential hospital bills. Office of the Assistant Secretary for Planning and Evaluation, Office of Health Policy, HHS; 2011 http://aspe.hhs.gov/health/reports/2011/ValueofInsurance/rb.shtml.
43. Dehmer SP. The Economics of a New Health Technology: an Evaluation of the Impact of Statins on Lifestyle Behaviors. Minneapolis [dissertation], MN: University of Minnesota, 2012.
44. Wei YC, George NI, Chang CW, Hicks KA. Assessing sex differences in the risk of cardiovascular disease and mortality per increment in systolic blood pressure: a systematic review and meta-analysis of follow-up studies in the United States. PLoS One. 2017;12(1):e0170218 10.1371/journal.pone.0170218. [PubMed: 28122035]
45. Benjamin EJ, Muntner P, Alonso A, et al. Heart disease and stroke statistics-2019 update: a report from the American Heart Association. Circulation. 2019;139(10):e56–e528. 10.1161/CIR.0000000000000659. [PubMed: 30700139]
46. Kypridemos C, Guzman-Castillo M, Hyseni L, et al. Estimated reductions in cardiovascular and gastric cancer disease burden through salt policies in England: an IMPACTNCD microsimulation study. BMJ Open. 2017;7(1):e013791 10.1136/bmjopen-2016-013791.
47. Huang Y, Van Horn L, Tinker LF, et al. Measurement error corrected sodium and potassium intake estimation using 24-hour urinary excretion. Hypertension. 2014;63(2):238–244. 10.1161/HYPERTENSIONAHA.113.02218. [PubMed: 24277763]
48. Park Y, Dodd KW, Kipnis V, et al. Comparison of self-reported dietary intakes from the automated self-administered 24-h recall, 4-d food records, and food-frequency questionnaires against recovery bio-markers. Am J Clin Nutr. 2018;107(1):80–93. 10.1093/ajcn/nqx002. [PubMed: 29381789]
49. Va P, Dodd KW, Zhao L, et al. Evaluation of measurement error in 24-hour dietary recall for assessing sodium and potassium intake among U.S. adults - National Health and Nutrition Examination Survey (NHANES), 2014. Am J Clin Nutr. 2019;109(6):1672–1682. 10.1093/ajcn/nqz044. [PubMed: 31136657]
50. Whelton PK, Carey RM, Aronow WS, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol. 2018;71(19):2199–2269. 10.1016/j.jacc.2017.11.005. [PubMed: 29146533]
51. Beauchamp GK, Bertino M, Engelman K. Failure to compensate decreased dietary sodium with increased table salt usage. JAMA. 1987;258(22):3275–3278. 10.1001/jama.1987.03400220075040. [PubMed: 3682116]

52. Janssen AM, Kremer S, van Stipriaan WL, Noort MW, de Vries JH, Temme EH. Reduced-sodium lunches are well-accepted by uninformed consumers over a 3-week period and result in decreased daily dietary sodium intakes: a randomized controlled trial. J Acad Nutr Diet. 2015;115(10):1614–1625. 10.1016/j.jand.2015.01.008. [PubMed: 25769746]

53. Sutherland J, Edwards P, Shankar B, Dangour AD. Fewer adults add salt at the table after initiation of a national salt campaign in the UK: a repeated cross-sectional analysis. Br J Nutr. 2013;110(3):552–558. 10.1017/S0007114512005430. [PubMed: 23286885]

Table 1.

Mean Dietary Sodium and Blood Pressure Reductions Associated With Policy Goal

Estimated values	30–39 years	40–49 years	50–59 years	60–69 years	≥70 years	≥30 years	Source
Baseline sodium consumption (mg/day)							
Men	4,583	4,090	4,202	3,627	3,351	4,048	[14]
Women	3,309	3,073	2,997	2,870	2,517	2,977	[14]
Men and women	3,937	3,573	3,582	3,229	2,872	3,488	[14]
Change in sodium consumption necessary to achieve 2,300 mg/day population average (mg/day)							
Men	−2,283	−1,790	−1,902	−1,327	−1,143	−1,380	Calculated
Women	−1,128	−1,048	−1,022	−979	−858	−1,015	Calculated
Projected sodium consumption after 10 years with full achievement of draft FDA industry goals (mg/day)							
Men	3,020	2,695	2,769	2,390	2,208	2,668	Calculated
Women	2,181	2,025	1,975	1,891	1,659	1,962	Calculated
Men and women	2,595	2,355	2,360	2,128	1,893	2,299	Policy target
Projected change in systolic blood pressure after 10 years with full achievement of draft FDA industry goals (mmHg)							
Men, hypertensive, black	−4.4	−4.6	−5.4	−5.2	−5.5	−5.0	[37]
Men, hypertensive, non-black	−2.7	−3.1	−3.8	−3.9	−4.2	−3.5	[37]
Men, normotensive, black	−3.2	−3.5	−4.2	−4.2	−4.6	−3.8	[37]
Men, normotensive, non-black	−1.5	−1.9	−2.7	−2.9	−3.3	−2.3	[37]
Women, hypertensive, black	−3.2	−3.5	−3.8	−4.1	−4.1	−3.7	[37]
Women, hypertensive, non-black	−2.0	−2.3	−2.7	−3.1	−3.2	−2.6	[37]
Women, normotensive, black	−2.3	−2.6	−3.0	−3.3	−3.4	−2.9	[37]
Women, normotensive, non-black	−1.1	−1.5	−1.9	−2.3	−2.5	−1.8	[37]

Note: Projected reductions in systolic blood pressure were calculated using the midpoint for each age range or 78 years for the ≥70-year-old group. Although policy effects are estimated for persons aged ≥35 years, sodium reduction calculations were calculated for persons aged ≥30 years to with how What We Eat in America[14] reported sodium consumption by age.

FDA, U.S. Food and Drug Administration.

Table 2.

Health, Budgetary, and Economic Outcomes With Sodium Reduction Policy

Outcomes (ages ≥35 years)	Without FDA goal achieved	With FDA goal achieved	10-year difference	(95% CI)
At 10 years				
SBP (mean, mmHg)	127.9	125.4	−2.4	(−2.4, −2.4)
SBP ≥140 mmHg, %	17.1	13.3	−3.8	(−3.9, −3.7)
Individuals with SBP ≥140 mmHg (millions)	31.4	24.5	−6.9	(−7.0, −6.8)
Treated SBP (mean, mmHg)	139.0	135.9	−3.1	(−3.1, −3.1)
Treated with SBP ≥140 mmHg, %	42.7	33.9	−8.9	(−9.0, −8.7)
Individuals with SBP 120–139 mmHg (millions)	62.7	54.6	−8.1	(−8.3, −8.0)
Over the 10-year period				
Person-years above goal (millions)	313.7	272.1	−41.6	(−42.0, −41.0)
Incident MI (thousands)	7,628	7,409	−218.9	(−241.1, −196.6)
Incident stroke[a] (thousands)	5,620	5,335	−284.5	(−307.1, −262.0)
Incident CVD events (thousands)	26,142	25,247	−895.2	(−939.5, −851.0)
Incident CVD death (thousands)	8,839	8,587	−252.5	(−273.0, −232.0)
CVD costs (billions $)				
Total	3,244	3,207	36.9	(−39.1, −34.7)
Private insurance	1,335	1,321	13.4	(−14.8, −112.9)
Medicare	1,307	1,289	18.4	(−20.0, −16.9)
Medicaid	103	102	0.9	(−1.2, −0.6)
Uninsured	424	421	3.5	(−4.2, −2.9)
Other insurance	74	73	−0.6	(−0.9, −0.4)
Total productivity (billions $)	106,469	106,487	18.2	(15.8, 20.7)

Note: Treated SBP indicates the mean systolic blood pressure for persons who are taking antihypertensive medications. The *Incident CVD events* rows combine incident MI, incident stroke, incident hospitalization for congestive heart failure, onset of angina pectoris, and onset of intermittent claudication. Private insurance includes commercial plans that cover medical expenses, as commonly obtained through employers or the private marketplace in the U.S. Medicare is a public program that primarily provides health insurance for persons aged ≥65 years in the U.S. Medicaid is a public program that provides health insurance to persons with inadequate income or resources to pay for health care in the U.S. Uninsured individuals have no insurance plan to pay for health care and are themselves responsible for the entirety of medical care bills. Other insured individuals may have coverage for medical expenses from a variety of less common sources, such as related to military service or insurance for work site or motor vehicle injury. The 95% CI was calculated from the distributional properties of the simulated population (i.e., mean and SE) and is a function of the sample size (1 million individuals). All costs are in undiscounted 2017 U.S. dollars.

[a]Incident stroke includes both incident ischemic and hemorrhagic stroke.

CVD, cardiovascular disease; FDA, U.S. Food and Drug Administration; MI, myocardial infarction; SBP, systolic blood pressure.

Table 3.

Health, Budgetary, and Economic Outcomes With Sodium Reduction Policy by Age and Sex Subgroups

	Difference attributable to sodium reduction policy			
Outcomes	**Ages 35–64 years**	**Ages ≥65 years**	**Men**	**Women**
At 10 years				
Individuals SBP ≥140 mmHg (millions)	−4.0	−2.9	−3.9	−3.0
Individuals with SBP 120–139 mmHg (millions)	−6.8	−1.3	−4.7	−3.4
Over 10 years				
Person-years above goal (millions)	−26	−16	−24	−18
Incident MI (thousands)	−92	−127	−156	−63
Incident stroke[a] (thousands)	−65	−220	−147	−137
Incident CVD events (thousands)	−265	−630	−530	−365
Incident CVD death (thousands)	−39	−214	−157	−95
CVD costs, total (billions $)	−12	−25	−22	−15
Total productivity (billions $)	5	13	12	6

Note: The *Incident CVD events* rows combine incident MI, incident stroke, incident hospitalization for congestive heart failure, onset of angina pectoris, and onset of intermittent claudication. All costs are in undiscounted 2017 U.S. dollars.

[a]Incident stroke includes incident ischemic and hemorrhagic stroke.

CVD, cardiovascular disease; MI, myocardial infarction; SBP, systolic blood pressure.

Table 4.

Results of Sensitivity Analyses on 10-Year Cumulative Differences Owing to Sodium Policy

Scenarios	Person-years SBP ≥140 mmHg (millions)	Incident MI (thousands)	Incident stroke (thousands)	Incident CVD death (thousands)	Disease costs (billions $)
Base case (primary analysis)	−42	−219	−285	−252	37
Policy variations					
2-year goal met only	−23	−113	−129	−134	21
10-year goal met immediately	−66	−336	−431	−389	61
Each person meets sodium goal	−46	−238	−295	−260	39
Effect of sodium reduction on BP (sodium sensitivity)					
Bibbins-Domingo et al.[10] (low bound)	−45	−220	−266	−238	36
Bibbins-Domingo et al.[10] (high bound)	−71	−356	−413	−366	57
Coxson etal.[8]	−42	−205	−247	−231	33
He et al.[39] (pooled estimate)	−42	−159	−178	−164	25
−25%	−31	−162	−209	−192	27
+25%	−52	−280	−350	−306	46
Disease costs					
−25%					27
+25					46

Note: The “Each person meets sodium goal” results reflect a sensitivity scenario in which all individuals reduce their sodium consumption at least to the stated goal over 10 years (2,300 mg/day), and those meeting or exceeding sodium reductions below the 2,300 mg/day target in <10 years under the base case scenario continue to do so. This contrasts from the base case scenario that involves population average sodium consumption being reduced to 2,300 mg/day. All costs are presented in undiscounted 2017 U.S. dollars.

CVD, cardiovascular disease; MI, myocardial infarction; SBP, systolic blood pressure.