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## The Importance of Population-Wide Sodium Reduction as a Means to Prevent Cardiovascular Disease and Stroke

### A Call to Action From the American Heart Association

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**B**lood pressure (BP)-related diseases, specifically, stroke, coronary heart disease, heart failure, and kidney disease, are leading causes of morbidity and mortality in the United States and throughout the world. In the United States, coronary heart disease and stroke are the leading causes of mortality, whereas heart failure is the leading cause of hospitalizations.<sup>1</sup> Concurrently, the prevalence of chronic kidney disease remains high and is escalating.<sup>2,3</sup> The direct and indirect costs of these conditions are staggering, over \$400 billion just for cardiovascular disease (CVD) in 2009.<sup>1,4</sup> The human consequences are likewise enormous.

The relation between BP and adverse health outcomes is direct and progressive with no evidence of a threshold, that is, the risk of CVD, stroke, and end-stage kidney disease increases progressively throughout the range of usual BP starting at a level of  $\approx 115/75$  mm Hg.<sup>5-7</sup> Overall, elevated BP is the second leading modifiable cause of death, accounting for an estimated 395 000 preventable deaths in the United States in 2005.<sup>8</sup> Worldwide, elevated BP accounts for 54% of stroke and 47% of coronary heart disease events; importantly, about half of these events occur in persons without hypertension.<sup>9</sup>

The 2020 goal of the American Heart Association (AHA) is to improve the cardiovascular health of all Americans by 20% while continuing to reduce deaths from CVD and stroke by 20%.<sup>4</sup> Two of the key metrics for ideal cardiovascular health are a BP of  $<120/80$  mm Hg and sodium consumption of  $<1500$  mg/d. The purpose of this advisory is 2-fold: first is to highlight the impressive body of evidence that links sodium intake with elevated BP and other adverse outcomes, and second, to serve as a call to action on behalf of the AHA

for individuals, healthcare providers, professional organizations, governments, and industry to address this major public health issue. See Table for key points.

### The Evidence

Excess intake of salt (sodium chloride) has a major role in the pathogenesis of elevated BP. Excess sodium intake also has BP-independent effects, promoting left ventricular hypertrophy as well as fibrosis in the heart, kidneys, and arteries.<sup>10</sup> Evidence on the adverse health effects of excess sodium intake includes results from animal studies, epidemiological studies, clinical trials, and meta-analyses of trials.<sup>11</sup> To date,  $>50$  randomized trials have tested the effects of sodium reduction on BP in adults. A meta-analysis<sup>12</sup> of these trials documented that a median reduction in urinary sodium of  $\approx 1800$  mg/d lowered systolic/diastolic BP by 2.0/1.0 mm Hg in nonhypertensive individuals and by 5.0/2.7 mm Hg in hypertensive individuals. In a subsequent meta-analysis of trials in children, a reduced sodium intake lowered mean systolic/diastolic BP by 1.2/1.3 mm Hg in children and adolescents and lowered systolic BP by 2.5 mm Hg in infants.<sup>13</sup> The benefits of sodium reduction in persons with poorly controlled BP are striking. In a recent trial of patients with resistant hypertension, reducing sodium intake by 4600 mg/d lowered systolic/diastolic BP by 22.7/9.1 mm Hg.<sup>14</sup>

Some of the most persuasive evidence on the effects of sodium on BP comes from rigorously controlled, dose-response trials.<sup>15-17</sup> Each of these trials tested at least 3 sodium levels, and each documented statistically significant, direct, progressive, dose-response relations. The lowest level of sodium intake in

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**Table. Key Points**

- Elevated blood pressure (BP) is a leading, preventable cause of mortality and morbidity in the United States and throughout the world.
- The relation of BP and adverse health outcomes is direct, progressive, consistent, continuous, independent, and etiologically relevant throughout the range of usual BP starting at a level of approximately 115/75 mm Hg.
- A diverse body of evidence has implicated excess sodium intake in the pathogenesis of elevated BP.
- Independent of its effects on BP, excess sodium intake adversely affects the heart, kidneys, and blood vessels.
- Current intake of sodium greatly exceeds 1500 mg/d, the upper level of intake recommended by the American Heart Association and the 2010 Dietary Guidelines Scientific Advisory Committee.
- The potential public health benefits of sodium reduction are enormous and extend to virtually all Americans.

each trial was  $\approx 1500$  mg/d, the level currently recommended by the AHA.<sup>4</sup> Importantly, the BP response to sodium reduction, while direct and progressive, was nonlinear. Specifically, decreasing sodium intake by  $\approx 900$  mg/d caused a greater reduction in BP when the starting sodium intake was  $\approx 2300$  mg/d than when it was  $\approx 3500$  mg/d. The DASH (Dietary Approaches to Stop Hypertension)-Sodium trial, the largest of the 3 major dose-response trials,<sup>18,19</sup> also documented that reduced sodium intake significantly lowered BP in each of the major subgroups studied (ie, nonhypertensive individuals, hypertensive individuals, men, women, African Americans, non-African Americans). The benefits of sodium reduction in non-hypertensive individuals were recently corroborated in the GenSalt feeding study, which documented that lowering sodium intake to  $\sim 1500$  mg/d reduced BP in  $\sim 2,000$  Asian adults with mean systolic/diastolic BP  $< 120/80$  mm Hg.<sup>20</sup>

Sodium reduction also blunts the age-related rise in BP. Because BP rises with age, about 90% of adults eventually become hypertensive.<sup>21</sup> The DASH-Sodium trial demonstrated that sodium reduction to a level of  $\approx 1500$  mg/d lowers BP more in older adults than younger adults.<sup>19</sup> Systolic BP decreased by 8.1 mm Hg in those aged 55 to 76 years, compared with 4.8 mm Hg for adults aged 23 to 41 years. In persons without hypertension, BP decreased by 7.0 mm Hg in those  $> 45$  years of age compared with 3.7 mm Hg in those  $\leq 45$  years of age. These results demonstrated that sodium reduction can lessen the rise in BP with age<sup>22</sup> and also confirmed the well-documented observation of a reduced age-related rise in BP in isolated populations with low sodium intake.<sup>23</sup> Consistent with this evidence, a major trial in the United States documented that a reduced sodium intake can prevent hypertension by  $\approx 20\%$ .<sup>24</sup>

Evidence supporting a direct relation of sodium intake and CVD is also accumulating. In a recent meta-analysis of observational studies, a higher sodium intake was associated with an increased risk of stroke and likely CVD.<sup>25</sup> To date, 3 trials conducted in general populations have reported the effects of reduced sodium interventions on CVD outcomes. Two of these trials tested lifestyle interventions that focused on reducing sodium intake, and 1 trial tested the effects of a reduced sodium/high potassium salt. In each instance, there was a 21% to 41% reduction in clinical CVD events in those who received a reduced sodium intervention (significant reduction in 2 trials<sup>26,27</sup>

and a nonsignificant trend in the third<sup>28</sup>). Hence, direct evidence from trials, albeit limited, is consistent with indirect evidence on the health benefits of sodium reduction.

Independent of its effects on BP, an increased sodium intake has other adverse effects. These include subclinical CVD (ie, left ventricular hypertrophy, ventricular fibrosis, diastolic dysfunction), kidney damage, gastric cancer, and disordered mineral metabolism (ie, increased urinary calcium excretion, potentially leading to osteoporosis).<sup>11</sup> It is well-established that sodium loading suppresses the systemic renin-angiotensin-aldosterone system by inhibiting renin release from the renal juxtaglomerular apparatus. Less well appreciated are findings that sodium loading increases oxidative stress and endothelial dysfunction and promotes mitogenic responses (fibrosis in heart, kidneys, and arteries) resulting in cardiac and vascular remodeling.<sup>10,29–33</sup>

With regard to arterial dysfunction, higher sodium intake is associated with greater increases in large elastic artery stiffness with aging,<sup>34,35</sup> and reducing sodium intake from moderate levels by  $\approx 50\%$  to less than  $\approx 1500$  mg/d reduces large elastic artery stiffness in otherwise healthy middle-aged and older adults with elevated systolic BP.<sup>36,37</sup> An acute increase in sodium intake has been shown to impair vascular endothelial function in young adults with normal BP.<sup>38</sup> Among middle-aged and older adults with elevated systolic BP, lower sodium intake is associated with enhanced vascular endothelial function, independent of BP or other risk factors.<sup>39</sup> A low sodium diet of  $\approx 1200$  mg/d improves endothelial function in overweight and obese adults with normal BP.<sup>40</sup> These findings have important clinical implications given that stiffening of the large elastic arteries, independent of BP, is a major independent risk factor for CVD and incident cardiovascular events,<sup>41,42</sup> whereas vascular endothelial dysfunction is associated with increased cardiovascular events and CVD mortality.<sup>43,44</sup>

Sodium-induced increases in BP may directly induce renal injury or accelerate kidney disease caused by other conditions such as diabetes mellitus or glomerulonephritis. However, excess sodium intake also has deleterious effects on the kidneys independent of increased BP. Studies in experimental animals and in human beings have shown, for example, that high sodium intake can cause glomerular hyperfiltration and increased albumin excretion, renal oxidative stress, and renal fibrosis independent of BP.<sup>45–47</sup> A direct association between sodium intake and urinary albumin excretion, independent of BP, has been observed in epidemiological studies.<sup>47</sup> In a trial of whites, blacks, and Asians with elevated BP, decreasing sodium intake from an average of  $\approx 3800$  mg/d to  $\approx 2500$  mg/d significantly reduced 24-hour urinary albumin excretion, an early marker of renal injury.<sup>48</sup> A retrospective analysis of patients with chronic kidney disease, with an average observation period of 3 years, showed that in patients with a sodium intake  $> 4600$  mg/d, the rate of decline in creatinine clearance and increase in proteinuria were greater compared with patients with a sodium intake  $< 2300$  mg/d, despite similar BP control.<sup>49</sup> Excess sodium intake also attenuates the beneficial effects of many antihypertensive drugs, especially the antiproteinuric effect of blocking the renin-angiotensin system.<sup>50</sup> Thus, there is considerable evidence linking increased sodium intake with kidney injury not only through

increased BP but also by effects that appear to be at least partly independent of BP.<sup>51</sup>

Some sodium intake is required. An Institute of Medicine Committee set 1500 mg of sodium per day as an adequate intake level, primarily to assure nutrient adequacy.<sup>52</sup> Based on the DASH-Sodium trial, it is apparent that Western type diets can provide this level of sodium intake and that such a diet also can provide adequate levels of other nutrients.<sup>53</sup> In 2005, the US Dietary Guidelines for Americans recommended a sodium intake of <2300 mg/d for the general adult population and stated that hypertensive individuals, blacks, and middle-aged and older adults would benefit from reducing their sodium intake even further to 1500 mg/d.<sup>53</sup> Because these latter groups comprise at least 50% of adults and perhaps as high as 70%,<sup>54</sup> and because ≈90% of US adults will develop hypertension over their lifetime, the goal should be 1500 mg/d, as recommended by the scientific advisory of the 2010 Dietary Guidelines Committee.<sup>55</sup> The health benefits apply to Americans in all groups, and there is no compelling evidence to exempt special populations from this public health recommendation. Although clinical research has identified groups that experience greater or lesser BP effects from sodium reduction, there is no practical clinical test to assess sodium sensitivity in individuals. Hence, it is not feasible, from a public health perspective, to classify individuals as sodium-sensitive or not.

### A Call to Action

The projected benefits of sodium reduction are substantial. Several studies have estimated the societal benefits of population-wide sodium reduction.<sup>56–58</sup> In the most recent and comprehensive set of projections, Bibbins-Domingo and colleagues<sup>58</sup> quantified the effects of 400 mg/d to 1200 mg/d reductions in sodium intake on a variety of relevant outcomes. A national effort that reduces sodium intake by 1200 mg/d should result in 60 000 to 120 000 fewer coronary heart disease events, 32 000 to 66 000 fewer strokes, 54 000 to 99 000 fewer myocardial infarctions, and 44 000 to 92 000 fewer deaths, and save 194 000 to 392 000 quality-adjusted life-years and \$10 to \$24 billion in healthcare costs annually. Even if average sodium intake is reduced by just 400 mg/d, the benefits would still be substantial and warrant implementation.

Accomplishing population-wide sodium reduction is similar to achieving other lifestyle modifications, in that a substantial public health approach will be required to facilitate environmental changes that support changes in individual behavior. Indeed, the need for an effective public health approach is even greater for sodium reduction than other lifestyle modifications. For example, in contrast to cigarette smoking, where usage is evident and deliberate by the consumer, the sodium content of our diets is not readily apparent.

More than 75% of consumed sodium comes from processed foods.<sup>59</sup> Even those who read labels are often left without realistic alternatives to high-sodium foods, and those who eat out, a behavior that has increased more than 200% from 1977 to 1995, are subjected to excessive sodium intakes from routinely served, processed foods.<sup>55</sup> Some food items are extremely high in sodium. However, from a public health perspective, the problem of excess sodium intake largely reflects the cumulative

intake of common foods that are only moderately high in sodium. Hence, any meaningful strategy to reduce sodium intake population-wide must involve the efforts of food manufacturers, food processors, and restaurant industries, a strategy that is being successfully implemented in other countries. For example, the United Kingdom has a vigorous salt reduction campaign, which has resulted in an estimated population-wide reduction in sodium intake of ≈10%.<sup>60</sup> Ongoing surveillance is necessary to evaluate the progress of such strategies.

Some scientists still question the evidence supporting population-wide sodium reduction. Common arguments include the absence of a major trial with hard clinical outcomes. It is well-known, however, that such trials are not feasible because of logistic, financial, and often ethical considerations. In fact, there is no trial of weight reduction or increased physical activity on hard clinical outcomes, and only 1 definitive trial of smoking cessation therapy on lung cancer.<sup>61</sup> It also has been argued that sodium reduction might be harmful.<sup>62</sup> However, the evidence for harm is unpersuasive, based largely on inferences from cohort studies with major methodological limitations, particularly, incomplete assessment of sodium intake and the potential for reverse causality.<sup>63</sup>

In 2010, the Institute of Medicine issued a report that provides a roadmap for lowering Americans' intake of sodium.<sup>64</sup> It was noted that for >40 years, efforts to reduce sodium intake of the US population have been unsuccessful. This absence of tangible progress reflects the lack of a substantive, multidimensional, environmentally focused strategic plan with measurable outcomes, joint-ownership, and accountability among the many stakeholders. Specifically, given the ubiquity of sodium in the food supply, the prior focus on encouraging individuals to select reduced-sodium products has been insufficient to meaningfully reduce sodium intake and achieve levels consistent with the Dietary Guidelines for Americans. Such efforts must be accompanied by an overall reduction of the level of sodium in the food supply. The Institute of Medicine made a series of recommendations, many of which involved regulatory actions (eg, setting mandatory national standards for the sodium content of foods). Such a strategy extends the voluntary approaches implemented in New York City.<sup>65</sup>

### Conclusion

A compelling and still increasing body of evidence supports the imperative for population-wide sodium reduction as an integral component of public health efforts to prevent CVD, stroke, and kidney disease. The potential public health benefits are enormous and extend to virtually all Americans. The AHA is committed to improving cardiovascular health of the whole population, as recently articulated in its 2020 strategic goals.<sup>4</sup> Successful sodium reduction requires action and partnership at all levels—individuals, healthcare providers, professional organizations, public health agencies, governments, and industry. The AHA urges a renewed and intensive focus on this critically important public health issue and looks forward to partnering with public and private organizations to achieve our shared goal of population-wide reduction in sodium intake.



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\*Significant.

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