SUMMARY Sixteen healthy, normotensive husband-wife pairs participated in a study to investigate the effect of reduction of dietary sodium intake (goal ≤ 60 mEq/day) on blood pressure. Sodium excretion decreased from a control average of 152.7 ± 10.1 (SE) mEq/day to 69.5 ± 4.5 mEq/day (p < 0.001). Results indicated significant decreases in both systolic (p < 0.001) and diastolic (p < 0.001) blood pressure after a period of sodium restriction. In the entire group, there was no significant change in potassium excretion (58.4 ± 3.2 vs 54.6 ± 3.5 mEq/day) or body weight (76.0 ± 2.8 vs 75.3 ± 2.7 kg). Although there was variability in the blood pressure response, the decrease in blood pressure was significantly correlated with the magnitude of sodium restriction (r = 0.36, p < 0.03). These results indicate that the blood pressure response to sodium restriction may not be limited to individuals with hypertension and that the response is heterogeneous in normotensive subjects. (Hypertension 5: 790-795, 1983)

KEY WORDS • blood pressure • sodium restriction • adults • nutrition • potassium

EPIDEMIOLOGIC studies have demonstrated that the level of blood pressure is linearly related to cardiovascular disease morbidity and mortality.1,2 Clinical and population studies indicate that a blood pressure reduction of as little as 4 mm Hg can diminish the incidence of vascular sequelae and decrease mortality in hypertensives.1-8 Several studies of various world populations have shown a positive relationship between high dietary sodium intake and the prevalence of high blood pressure,5-12 but other studies have failed to show this relationship.13,14 Many individuals living in societies with high sodium intake fail to develop hypertension. Furthermore, when the high dietary salt/high blood pressure relationship is demonstrated for a population, the degree of blood pressure elevation is not always correlated quantitatively with the level of sodium in the diet.

The case for sodium restriction has been popularized,15 and the Food and Drug Administration has responded with a series of articles16-19 addressing the problems inherent in dietary sodium restriction for the entire population. Scientists familiar with the treatment of hypertension are divided on the wisdom of advocating low sodium diets for the general population,20 with some suggesting that it may be a noble goal for hypertension-prone individuals but may not be attainable given the current American life style.21-23 On the other hand, evidence has recently been presented that suggests the desirability of nonpharmacologic approaches to the treatment of hypertension.24 Lobbying groups have been formed to influence the legislative branch of the federal government to enact laws affecting the sodium content of foods and the labeling of food products.25 The implication of these activities is considerable. In addition to presenting a major public health issue, the socioeconomic impact of such legislation is great.

The following study was designed to investigate the effect of sodium restriction on blood pressure in healthy, free-living, normotensive couples. In addition, it was to be determined whether moderate sodium restriction could be maintained in these individuals for a period of 3 months. The goal of 60 mEq/day of dietary sodium was chosen as a level that could be attained with a minimum of effort and expense in normotensive subjects. To enhance the likelihood of compliance, a personalized approach to dietary counseling by a registered dietitian was utilized in these studies that involved the whole family.
BLOOD PRESSURE RESPONSE TO SODIUM RESTRICTION/Miller et al.

Methods

Normotensive school-age identical twin pairs and their families were recruited from the existing twin panel in the Indiana University School of Medicine, Department of Medical Genetics, as part of an ongoing investigation of the effects of dietary sodium modification on blood pressure. The protocol was approved by the Indiana University Medical Center Human Use Committee. Potential participants were sent a letter explaining that the investigators were interested in dietary factors and blood pressure and that the study involved several urine collections and blood pressure determinations that would be conducted in the home. They were told that, after collection of control data, there would be alterations in their diet that would involve no caloric restrictions, but specific mention of sodium restriction was avoided.

Study Protocol

Blood Pressure and Weight Measurements

Three blood pressure measurements were obtained on each home visit using the Hawksley Random Zero blood pressure device (Hawksley, England) after the subject had been sitting in a comfortable position for approximately 5 minutes. The average of the last two of three blood pressure measurements was used for analysis. This use of sequential indirect blood pressure measurement in the home environment by a single observer, with discard of the first of the three readings, was intended to minimize the confounding effect of the orienting reflex discussed by Pickering. All individuals recording blood pressure in this study were trained and certified in blood pressure measurement according to the standards of the High Blood Pressure Program of the Indiana State Board of Health.

Body weight was measured with a portable electronic digital scale (Hanson Memorie, Hanson Scale Co., Shubuta, Mississippi), which was periodically checked against standard clinical scales.

Dietary Instruction

After collection of the baseline data, families received instruction to aid them in restricting their dietary sodium intake to 60 mEq/day or less. Instruction was designed to build on a basic diet instruction booklet, similar to that often used for diet instruction in the clinical setting, and the American Heart Association Cookbook, Cooking Without Your Salt Shaker. This instruction was performed by a registered dietitian in the family home, with the primary food preparer and any other interested family members present. Since this was the first time that the details of the requested dietary modification, i.e., reduction in sodium intake, had been presented to the families, they were given the option of declining to participate in the sodium restriction phase. Of the 30 families initially recruited, 14 families declined to continue; the primary reason cited was a reluctance to alter their food preparation techniques sufficiently to restrict sodium to 60 mEq or less.

Families who elected to continue the study received additional dietary information. A 2-week stabilization period was allowed for the identification of potential problems with dietary adherence. During this phase of the study several dietary instruction sessions were conducted in each family’s home. Sincere efforts were made to customize the diet plan to the life styles and food preferences of the family. Topics and handouts regarding such areas as grocery shopping, eating out, fast foods, and food preparation were covered by the dietitian in an order determined to be most effective for maintaining compliance for a particular family.

Data Collection

Baseline data involved the collection of five 24-hour urine samples and concomitant blood pressure measurements on each family member over a period of 1 month prior to any discussion of sodium restriction. On each day of urine collection, blood pressure and weight were obtained as described above by a research assistant in each family’s home. These five blood pressure, weight, and 24-hour sodium determinations form the control data to which later determinations were compared. Each participant completed three 24-hour food records during this period to identify potential problems with dietary modification.

Families agreeing to participate in the sodium-restricted diet phase of the study were scheduled for a medical history and physical examination by a physician-investigator prior to initiation of salt restriction. This was to rule out any possible health problem that would be adversely affected by salt restriction. No family was ruled ineligible due to health problems. Elevated blood pressure was not a criterion for exclusion, although all volunteers were normotensive. At the end of the 2-week stabilization period, all adults collected a 24-hour urine sample. If they were at the goal of 60 mEq sodium excretion, they were entered into the dietary intervention phase. If they had not reached this goal the protocol included an additional 2 weeks of dietary stabilization and counseling. Only one family required a longer stabilization period.

During the dietary intervention phase, adults collected urine samples every other week for a period of 12 weeks. Weight and blood pressure measurements were obtained by the research assistant in the home on the day of urine collection. Participants were given the results of their sodium excretion as soon as they were available, generally within 2–3 days.

Laboratory Methods

Urine samples were analyzed for sodium, potassium, and creatinine using standard flame photometry and autoanalyzer techniques. A urine sample was considered to be representative if the creatinine excretion was ± 20% of the mean creatinine of all complete baseline urine collections for that individual. Overall, 80% of urine collections were determined to be complete according to this criteria.
Statistical Analysis

Data base management was accomplished by SIR (Scientific Information Retrieval) for ease in handling missing or incomplete data. This package will produce an average of all available data for each individual under a given condition, thus overcoming the potential problems inherent in incomplete urine collections. This derived average of all complete urine collections was then the variable used in subsequent statistical analysis. Routine statistical analyses, including repeated measurements of analysis of variance, multiple linear regression, and paired t-tests, where appropriate, were performed using SPSS (Statistical Package for the Social Sciences).

Results

Of the 16 families who completed the study, all were white. The mean age of the fathers was 40.0 ± 2.5 (se) years (range 31-69 years) and that of the mothers was 37.2 ± 1.9 years (range 29-54 years). Figure 1 presents the blood pressure data collected during each phase of the study, while figure 2 displays electrolyte and weight determinations for all adults. The first five control blood pressure determinations were not significantly different when evaluated by repeated measures analysis of variance, indicating that there was no significant decrease in blood pressure during the baseline acclimatization period. Therefore, the subsequent decrease in systolic (p < 0.001) and diastolic (p < 0.001) blood pressure seen during the low sodium diet period was attributed to the dietary intervention. Sodium excretion decreased from an average control level of 152.7 ± 10.1 mEq to an average of 69.5 ± 4.5 mEq during the dietary intervention period. Figure 2 shows that neither potassium (58.4 ± 3.2 vs 54.6 ± 3.5 mEq/day) nor weight (76.0 ± 2.6 vs 75.3 ± 2.7 kg) changed substantially during the study period in the combined male and female sample.

Table 1 presents the data separately for men and women, comparing data from the control period to the diet intervention period for each person. The probability levels refer to paired t-test comparisons, although the standard errors reported are for the group under each condition. Both sexes responded to sodium restriction with decreases in blood pressure, and only men showed a slight (mean = 1.2 kg) weight loss. Data from one woman was discarded due to incomplete urine collections.

Figure 3 shows the individual blood pressure responses in this population. The wide range of blood pressure response is striking. While the majority of the individuals (24/31) showed a decrease in systolic blood pressure, a substantial number (7/31) showed no decrease. In an attempt to assess the relative importance of these blood pressure changes, the control pressures (n = 5) were compared to the intervention pressures (n = 6) for each individual. Of the seven individuals who showed an increase in systolic blood pressure...
TABLE 1. Blood Pressure Response to Dietary Sodium Changes in Adult Men and Women (mean ± so error)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Women (n = 15)</th>
<th>Men (n = 16)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-hour urine data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (mEq/day)</td>
<td>130.20±8.47</td>
<td>59.69±5.65</td>
<td>0.001</td>
</tr>
<tr>
<td>Potassium (mEq/day)</td>
<td>56.23±4.22</td>
<td>51.18±3.67</td>
<td>NS</td>
</tr>
<tr>
<td>Creatinine (g/day)</td>
<td>1.08±0.07</td>
<td>1.00±0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Anthropometric data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>67.00±3.20</td>
<td>66.90±3.22</td>
<td>NS</td>
</tr>
<tr>
<td>Surface area (m²)</td>
<td>1.72±0.04</td>
<td>1.72±0.04</td>
<td>NS</td>
</tr>
<tr>
<td>Blood pressure data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic (mm Hg)</td>
<td>102.12±2.18</td>
<td>98.68±1.67</td>
<td>0.02</td>
</tr>
<tr>
<td>Diastolic (mm Hg)</td>
<td>70.89±1.72</td>
<td>68.15±1.29</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Probability (p) levels refer to results from paired t tests. Results are means ± SEM.

pressure, the change was statistically significant for only one, while for six of the 24 individuals, the decrease was significant (p < 0.05). For diastolic pressure, no one had a statistically significant increase, while the decrease was significant for six persons (p < 0.05). This variability in response was also reflected in the correlation of the change in blood pressure with the change in sodium excretion (systolic, r = 0.36, p < 0.03; diastolic, r = 0.36, p < 0.02). Multiple linear regression was performed to relate the change in blood pressure to the control values of sodium intake, weight, sex, age, and initial blood pressure. Only the initial blood pressure level was significant in predicting the response of both systolic (p < 0.005) and diastolic blood pressure (p < 0.003) in this population. These analyses indicate that individuals with higher initial blood pressures were more likely to respond to the intervention with a decrease in blood pressure.

To examine changes in blood pressure during the baseline period that might represent adaptation to the measurement procedure and thus could have contributed to the changes observed during the intervention period, the slopes of the regression of the five baseline blood pressure measurements vs time were computed.
for each individual, separately for systolic, diastolic, and mean arterial pressures. The means ± standard errors of the resulting coefficients were 0.13 ± 0.44 systolic, -0.37 ± 0.36 diastolic, and -0.21 ± 0.36 for mean arterial pressure, results that are not significantly different from zero. There was clearly no downward trend with time among the first five baseline blood pressures. Only one person of the 31 studied had significantly negative slopes for all three pressures, a result that could be expected by chance in this population.

Discussion

Although this was an open, uncontrolled study, to our knowledge it represented the first attempt to investigate the blood pressure response to moderate sodium restriction in healthy normotensive adult men and women. The results are particularly meaningful since the potential confounding variables of weight and potassium excretion did not change substantially during the course of the study and there was no evidence of blood pressure change or adaptation during the control period.

The magnitude of the blood pressure decrease in the present study was not great, but was consistent and statistically significant (4.0 ± 1.1/3.2 ± 1.0 mm Hg). However, recent results from a large clinical trial showed a 20% decrease in mortality in hypertensives with initial diastolic pressures 90–104 mm Hg who received aggressive medical care compared to usual care, and the mean diastolic blood pressure difference between the two groups in that trial was only 4–5 mm Hg.32 According to the Framingham Study data, a decrease of 8 mm Hg diastolic pressure would produce a change in death rate on the order of 10% to 15%.6 There are few studies that have investigated the relationship of low sodium diets to blood pressure in hypertensive individuals. Kempner11 first reported a substantial blood pressure decrease in hypertensive patients treated with his low protein, rice diet, which was fortuitously low in sodium. The introduction of diuretic therapy brought low sodium diet therapy for hypertensives to a virtual halt, although three recent prospective clinical investigations have demonstrated significant blood pressure reductions for hypertensive patients with dietary sodium intakes of 75–90 mEq/day.32–34 A randomized controlled trial of low sodium diet therapy in mild hypertension33 reinforces the benefits observed in previously reported studies of sodium restriction in the treatment of hypertensives.32–34

A recent multifactor intervention trial presented evidence that suggested that pharmacologic control of blood pressure may not be advantageous for all hypertensives.24 Dietary intervention in the prevention and treatment of hypertension has considerable appeal. The risks and side effects of drug therapy may be reduced. Sodium restriction may provide a cost advantage over medication, particularly considering that the size of the hypertensive population involved in the United States may exceed 30,000,000 people. It is also possible that lowering dietary sodium intake may decrease the risk of developing the disease for susceptible individuals.

There is a paucity of information on the blood pressure response to sodium restriction in normotensive individuals. Cooper and colleagues27 showed that blood pressure was significantly lower in children eating ≤ 117 mEq/day compared with those eating ≥ 140 mEq/day. Gillum et al.28 failed to demonstrate any blood pressure change in 80 school children who received dietary instruction because their blood pressures were > 95th percentile for age. In short-term studies, it has not been shown that lowering sodium intake of normotensive individuals to low levels lowers their blood pressure.39 However, even potent antihypertensive drugs may have little or no effect on the blood pressure of normotensive subjects. The present study establishes the feasibility of moderate sodium restriction in free-living individuals, and this should permit further investigation of the relationship of sodium restriction to blood pressure. Other authors have demonstrated blood pressure increases with sodium supplementation of the usual diet,40,41 but these studies are subject to the criticism that the resulting intakes are greater than those encountered in free-living individuals.

It should be emphasized that the subjects in the present study were all healthy individuals who volunteered to participate in this study because they had twin children and who had no evidence of cardiovascular disease. Thus, one might expect to find little or no blood pressure response to this degree of sodium restriction in the study population. Instead, the results are compatible with those found in studies of hypertensives where most, but not all, patients responded with a decreased blood pressure22,34 or required less medication for blood pressure control.35 Potential reasons for differences in sodium sensitivity in normal individuals are discussed elsewhere.42 Our data suggest that response to sodium restriction may not be related to the hypertensive disease process per se but rather may be due to the complex response mechanisms responsible for blood pressure control. Additional investigations in this area will be required to establish a causal relationship. The blood pressure response was heterogeneous even in this population, as displayed graphically in figure 3. This fact is reflected by the magnitude of the correlation between the degree of sodium restriction and change in blood pressure. This observation is consistent with current understanding of the multifactorial control of blood pressure. Further investigations are planned to determine the relative importance of familial factors, such as a history of essential hypertension, to the blood pressure response.

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