Hormonal Adaptation to the Stresses Imposed Upon Sodium Balance by Pregnancy and Lactation in the Yanomama Indians, A Culture Without Salt

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SUMMARY. The Yanomama Indians of northern Brazil and southern Venezuela have been identified as a "no-salt" culture. In this study, data were obtained to determine in this population the adjustments of sodium-related hormones to the stresses imposed upon sodium balance by pregnancy and prolonged lactation. Controls against the possibility that findings in the Yanomama were ethnic rather than dietary were provided by similar observations in the Guaymi Indians of Panama, who have free access to salt. Urinary concentrations of sodium were approximately 1 mEq/l in male and female Yanomama, with 24-hour excretion rates in the males averaging 1 mEq/l, similar to our prior observations. The pregnant Yanomama had exceeding high urinary concentrations of aldosterone. These were associated with higher plasma renin activities and serum aldosterone concentrations than in all other subjects. Although pregnant Guaymi had elevations of serum and urinary aldosterone, these were significantly lower (p < 0.001) than those of the Yanomama. Prolonged lactation in the Yanomama was associated with elevation of plasma renin activity and serum and urinary aldosterone concentration compared with the Guaymi, but were not higher than those in nonlactating Yanomama females. The findings suggest that pregnancy in a salt-poor environment is associated with an exaggerated augmentation of hormonal responses that enhance positive sodium balance.

DURING PREGNANCY, there are marked increases in maternal peripheral blood of renin substrate, renin concentration, renin activity, angiotensin and angiotensinase.\textsuperscript{1, 2} Simultaneously, secretion and excretion of aldosterone increase.\textsuperscript{3, 4} This interlocking hormonal system of renin-angiotensin-aldosterone has a major influence on sodium retention. The possible importance of these hormonal responses is emphasized by the fact that the products of normal pregnancy — fetus, placenta, associated membranes, and amniotic fluid, plus growth of breasts and uterus — have been estimated to require an accumulative retention of 500–700 mEq of sodium.\textsuperscript{5, 6} The subsequent lactation, often extending over 2–3 years in unacculturated societies, results in a daily loss of 5–7 mEq of sodium/l of breast milk. We previously reported our observations on blood pressure and hormonal adjustments in male Yanomama Indians of northern Brazil and southern Venezuela, a group with no added dietary salt.\textsuperscript{7} In this follow-up, we present the results of an attempt to study in this same group the adjustments of the renin-aldosterone system to the stresses imposed on sodium balance by pregnancy and prolonged lactation. For comparison, we made similar observations on the Guaymi Indians of Panama, who have had unlimited access to salt for many generations. Although the difficulties of field work among such remote populations resulted in small sample sizes, the critical findings are so striking that their validity seems secure.

Materials and Methods

Subjects

Yanomama Indians are distributed in some 150 villages in an area of approximately 100,000 square miles in northern Brazil and southern Venezuela.\textsuperscript{8, 9} Sustained contacts with non-Indians, primarily missionaries and government post workers, began in the early 1950s. Genetic and linguistic data indicate a high degree of isolation for at least the past several thousand years.\textsuperscript{10} The diet of the Yanomama is primarily vegetarian, with the cooking banana, \textit{Musa paradisica}, serving as the major staple. This is irregularly supplemented by additions of game, fish, insects and wild vegetable food; protein intake appears adequate.\textsuperscript{11} The tribe has had no access to sodium chloride except when introduced by Caucasians in these recent contacts since 1950. Analyses of samples obtained in these field studies confirm a paucity of sodium in nonanimal sources of food in their diet, with probably the highest contribution provided by the cooking ashes that adhere to the peeled plantains and other foods after roasting. The Yanomama subjects for the present study were inhabitants of one of the same villages (15 QR; see map in Tanis et al.\textsuperscript{12}) in

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which our previous investigation had documented that there was no access to sodium chloride. The field work to be described was conducted in August 1976.

Controls against the possibility that the findings in the Yanomama were ethnic rather than dietary in origin were provided by earlier studies of the Guaymi Indians of Panama, a group of at least 30,000 persons living in the cordillera of western Panama and eastern Costa Rica. Although the Guaymi Indians have had many generations of contact with acculturated people, the nature of the people and the relative inaccessibility of their villages have resulted in comparative isolation, as documented by genetic data. The diet of the Guaymi consists primarily of rice, beans, yams and tropical fruits, with sporadic additions of meat from their livestock. Salt is added to cooked vegetables and used for preservation of meat. The samples in question were collected in the villages designated as 32 A-D and 32 E-G. The field work was conducted in late June 1975.

Blood Pressure

Measurements were made using either a Tycos Aneroid sphygmomanometer or a Bauman mercury sphygmomanometer. No significant difference was discerned between the two instruments. Measurements were made on the right arm with the subjects sitting quietly. All measurements were made between 8-10:00 a.m.

Urinary Excretion of Aldosterone, Creatinine, Potassium and Sodium

Putative 24-hour urine samples could be collected in the field from males, but for a variety of reasons this was impractical for females, and only spot samples were obtained. These were collected from the subjects, both Yanomama and Guaymi, between 8:00-10:00 a.m. after measurement of blood pressure and venipuncture for blood samples. The urine samples were transferred to small plastic bottles that contained thymol crystals. These were refrigerated in styrofoam chests that contained ice until reaching the laboratory, usually within 3-4 days of collection. Samples were then frozen until analyzed.

For the Yanomama males, similar spot samples were obtained between 8-10:00 a.m. The males were then given 2-l plastic containers and instructed to void all urine into the container, including the first sample the next morning. The 24-hour collections were measured, aliquots transferred to plastic bottles containing thymol crystals, and refrigerated as described. For the Guaymi males, the only samples obtained were 24-hour collections; these were processed as described for the Yanomama males.

Control male subjects consisted of members of the expedition on a normal diet augmented by table salt ad lib. For comparison with the Yanomama studies, both spot and 24-hour urine samples were obtained. Twenty-four-hour urine collections only were obtained from the expeditionary control subjects for comparison with the results of the Guaymi studies.

Breast Milk Samples

Breast milk samples were collected in plastic bottles from lactating Yanomama women who used manual expression to produce the sample after cleansing of the breasts with soap and water, followed by rinsing with de-ionized water. Tincture of Merthiolate 1/1000 and chloromycetin-amphotericin B solution were added to the samples in amounts of 2 drops and 1 drop per ml of breast milk, respectively. The samples were refrigerated in ice until reaching the laboratory. Samples were then frozen until analyzed. No breast milk samples were obtained on the Guaymi females. However, lactation extends for 2-3 years in this culture, a period of comparable duration to the Yanomama.

Blood Samples

As in the previous study, blood samples were obtained between 8-10:00 a.m. upon completion of the spot urine collections. The subjects had been ambulatory for approximately 2 hours before samples were obtained. The field conditions and the informal lifestyle of the subjects prevented rigid adherence to a prescribed protocol for rest or activity before sampling.

For renin, blood was collected in EDTA-containing vacutainers; these were chilled in ice water and promptly centrifuged in a hand-driven centrifuge. The harvested plasma was placed in styrofoam chests that contained ice and maintained cold until reaching the laboratory. Samples were then frozen until assayed.

For aldosterone, the blood was collected in vacutainers without additive, permitted to clot and retract, and then centrifuged. The harvested sera were maintained cold until reaching the laboratory where samples were frozen until analyzed.

Because historical data were unreliable, pregnancy was determined using urine and plasma of all females from whom samples were obtained, both lactating and nonlactating.

Analyses

Urine sodium, potassium, chloride, creatinine and aldosterone were analyzed as previously described. Serum and breast milk concentrations of sodium and potassium were determined by flame photometer. Serum aldosterone concentration was measured by radioimmunoassay. Plasma renin activity was determined by the method of Cohen et al. Normal values for plasma renin activity measured in 2-hour (8-10:00 a.m.) continuously ambulatory males and females (ages 22-62 years) are 4.3 ± 0.5 ng/ml/hr (mean ± SEM) (general diet) and 17.7 ± 2.20 ng/ml/hr (mean ± SEM) (10 mEq Na+ diet for 3 days) (n = 24). Presence of pregnancy was determined by simultaneous analyses of urine (rat ovarian hyperemia) and plasma (radioreceptor assay of human chorionic gonadotropin) from all female subjects. All statements concerning the significance of an observed difference are based upon a two-tailed t test.
TABLE 1. Physical Characteristics and Results of Laboratory Analyses in Male Guaymi and Yanomama Indians and in Male Expeditionary Controls

<table>
<thead>
<tr>
<th>Variables</th>
<th>Guaymi</th>
<th>Controls</th>
<th>Yanomama</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indians</td>
<td>n</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>4</td>
<td>36.0 ± 5.6</td>
<td>2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>4</td>
<td>62.3 ± 7.5</td>
<td>2</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
<td>4</td>
<td>116.0 ± 4.3/</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>73.8 ± 13.6</td>
<td></td>
</tr>
<tr>
<td>Pulse (beats/min)</td>
<td></td>
<td>67.0 ± 1.4</td>
<td>2</td>
</tr>
<tr>
<td>Serum aldosterone (ng/dl)</td>
<td>4</td>
<td>10.3 ± 6.6</td>
<td>2</td>
</tr>
<tr>
<td>Plasma renin activity (ng/ml/hr)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*This high standard deviation is due to one outlying value of 376.
†This high standard deviation is due to one outlying value of 266.
‡This high standard deviation is due to one outlying value of 227.3.
§This high standard deviation is due to one outlying value of 29.1.

Results

Blood Pressure

The mean systolic and diastolic blood pressures are listed in tables 1 and 2. For the male Yanomama Indians, within the obvious limits of small sample size, the data are similar to our previous observations. Mean pressures for the Guaymi males are similar. For the females, using the two-tailed t test, blood pressures were not significantly different between the pregnant and nonpregnant (lactating and nonlactating) Yanomama females, nor were these different for the pregnant vs nonpregnant Guayami females. Small sample size precludes any generalized conclusion, however.

Urinary Excretion of Sodium, Potassium and Creatinine

Using the criterion of the previous study for total creatinine, the 24-hour samples of the males (table 1) were judged to be essentially complete. The 24-hour excretions for sodium and potassium for the controls are within the normal range and similar to our previous data. For the Yanomama males, the data on 24-hour excretions of the two minerals reaffirm our prior finding of an excretion of sodium of approximately only 1 mEq/24 hours, with large quantities of potassium. In contrast, the Guaymi males, with an observed liberal use of added salt in the diet, excreted quantities of sodium less than the expeditionary controls, but of a magnitude (66.8 ± 8.9 mEq/24 hours) to reflect a reasonably generous intake. The 24-hour creatinine values for the Yanomama are significantly higher than reported in our previous paper. Although the present Yanomama males are an average of 6.5 kg heavier than the first subjects, this is not sufficient reason for the difference, which remains unexplained. Nevertheless, this difference does not invalidate the data of primary interest, which are the minimal quantities of urinary sodium in the collected samples.

The purpose of the spot urines upon the Yanomama males and expeditionary controls was to provide an approximation to how well concentrations of various urinary constituents in spot samples reflected the excretion of these same components in 24-hour urine collections from the same subjects. For sodium and potassium, the concentrations compared favorably with the excretions determined in the 24-hour collections.

In all samples from the Yanomama females, the concentration of sodium in the spot samples of both pregnant and nonpregnant subjects was a mean of approximately 1 mEq/l (table 2), similar to values of the spot samples from their male counterparts. Concentrations of potassium were uniformly high in all samples from the Yanomama females. The resultant Na/K ratios ranged between 0.003 for pregnant and nonpregnant, lactating females to 0.007 for those neither pregnant nor lactating.
TABLE 1. (Continued)

<table>
<thead>
<tr>
<th>Yanomama</th>
<th>Variables</th>
<th>Yanomama (spot samples)</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Mean ± sd</td>
<td>n Mean ± sd</td>
<td>n Mean ± sd</td>
</tr>
<tr>
<td>3</td>
<td>38.3 ± 11.2</td>
<td>6 0.5 ± 0.2</td>
<td>3 99.0 ± 59.6</td>
</tr>
<tr>
<td>3</td>
<td>74.2 ± 9.5</td>
<td>3 72.0 ± 32.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120.0 ± 2.0</td>
<td>6 0.002 ± 0.001</td>
<td>3 1.4 ± 0.7</td>
</tr>
<tr>
<td>3</td>
<td>70.0 ± 2.0</td>
<td>3 1.8 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>68.7 ± 8.1</td>
<td>3 1.8 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>21.6 ± 9.8</td>
<td>3 11.4 ± 1.9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.6 ± 1.9</td>
<td>3 165.4 ± 67.7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>76.4 ± 18.0</td>
<td>6 6.1 ± 1.0</td>
<td>6 79.9 ± 93.6†</td>
</tr>
<tr>
<td>3</td>
<td>2.3 ± 1.2</td>
<td>3 1.3 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.8 ± 0.1</td>
<td>3 9.9 ± 8.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11.3 ± 2.5</td>
<td>3 6.1 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11.4 ± 2.5</td>
<td>3 6.1 ± 1.0</td>
<td></td>
</tr>
</tbody>
</table>

This table shows the results of laboratory analyses of blood and spot urine samples in female Guaymi and Yanomama Indians, including plasma renin activity and urinary aldosterone levels.

TABLE 2. Physical Characteristics and Results of Laboratory Analyses of Blood and Spot Urine Samples in Female Guaymi and Yanomama Indians

<table>
<thead>
<tr>
<th>Variables</th>
<th>Guaymi</th>
<th>Yanomama</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonpregnant</td>
<td>Pregnant</td>
</tr>
<tr>
<td></td>
<td>n Mean ± sd</td>
<td>n Mean ± sd</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9 25.0 ± 4.7</td>
<td>7 21.6 ± 3.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>9 55.6 ± 7.6</td>
<td>7 58.1 ± 7.8</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
<td>9 113.6 ± 7.9/ 74.9 ± 9.4</td>
<td>7 114.6 ± 7.1/ 69.7 ± 8.1</td>
</tr>
<tr>
<td>Pulse (beats/min)</td>
<td></td>
<td>16 85.1 ± 17.0</td>
</tr>
<tr>
<td>Serum aldosterone (ng/dl)</td>
<td>8 16.5 ± 6.3</td>
<td>5 85.5 ± 51.1</td>
</tr>
<tr>
<td>Plasma renin activity (ng/ml/hr)</td>
<td></td>
<td>14 6.2 ± 4.1</td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na⁺ (mEq/l)</td>
<td>9 119.0 ± 52.7</td>
<td>7 77.8 ± 30.0</td>
</tr>
<tr>
<td>K⁺ (mEq/l)</td>
<td>9 138.0 ± 46.6</td>
<td>7 105.8 ± 47.1</td>
</tr>
<tr>
<td>Na⁺/K</td>
<td>9 1.0 ± 0.6</td>
<td>7 0.9 ± 0.8</td>
</tr>
<tr>
<td>Creat (mg/ml)</td>
<td>9 0.9 ± 0.3</td>
<td>7 0.6 ± 0.3</td>
</tr>
<tr>
<td>Ald (ng/ml)</td>
<td>9 7.5 ± 5.5</td>
<td>7 92.1 ± 110.1†</td>
</tr>
<tr>
<td>Ald/Creat</td>
<td>9 8.3 ± 5.7</td>
<td>7 128.2 ± 97.2</td>
</tr>
</tbody>
</table>

*This high standard deviation is due to one outlying value of 256.
†This high standard deviation is due to one outlying value of 524.
‡This high standard deviation is due to one outlying value of 330.
§This high standard deviation is due to one outlying value of 264.
In the Guaymi females, concentrations of sodium in terms of mEq/l in the spot samples were also similar to those observed in males and were not significantly different between pregnant and nonpregnant subjects. The Na/K ratios in these spot samples approximated those obtained in the 24-hour excretions of the male Guaymi.

Concentrations of Sodium and Potassium in Serum and Breast Milk

Mean concentrations of serum sodium and potassium were $141.1 \pm 4.1$ mEq/l and $5.3 \pm 0.5$ mEq/l, respectively, for the Yanomama subjects and did not differ significantly between males and females. For the expeditionary controls, mean serum concentrations of sodium were $143.0 \pm 2.5$ mEq/l and $5.7 \pm 0.5$ mEq/l, respectively.

In breast milk the concentrations of sodium ranged between 5-9 mEq/l and potassium between 9-17 mEq/l. These are similar to values reported for contemporary subjects.

Serum and Urinary Aldosterone

The outstanding finding was the exceedingly high concentration of aldosterone in the urine of the pregnant Yanomama women (table 2, fig. 1). Values ranged from 534-651 ng/ml, far greater than the concentrations observed in the pregnant Guaymi women ($92.1 \pm 110.1$ ng/ml) or in the Yanomama males for either the 24-hour collections ($72.5 \pm 17.2$ ng/ml) or the spot samples from these subjects ($79.9 \pm 93.6$ ng/ml). Whether viewed in terms of concentrations of that mineralocorticoid in the urine or in relation to simultaneous concentrations of urinary creatinine (table 2, fig. 2), the excretion rates are extremely high in the pregnant Yanomama, probably reflecting a simultaneously extraordinary rate of secretion of the hormone by the adrenal glands. For the nonpregnant Yanomama females, concentrations of urinary aldosterone were significantly greater than those of the Guaymi females with liberal access to salt. Both the Yanomama and Guaymi pregnant females had elevated serum aldosterone levels, with concentrations of $155.9 \pm 245.3$ ng/dl and $85.5 \pm 51.1$ ng/dl, respectively. The relatively high concentrations of serum aldosterone in the Yanomama male compared with the nonpregnant Yanomama female, are due primarily to two subjects with values of 273 and 376 ng/dl. However, values for the nonpregnant Yanomama females were elevated compared with the males and nonpregnant females of the Guaymi subjects and the expeditionary control subjects.

Plasma Renin Activity

Pregnant Yanomama women had the highest levels of plasma renin activity, with values of 18.6-32.4 ng/ml/hr. For the Yanomama males, the values were similar to those found in our prior study and approached the values of control subjects after 3 days of...
a 10-mEq Na⁺ diet.¹⁷ Nonpregnant, nonlactating Yanomama females had similar, but slightly lower, values (6.2 ± 4.1 ng/ml/hr), as did lactating, nonpregnant females (5.0 ± 2.6 ng/ml/hr). The values for the pregnant Yanomama women were significantly different from those of the other two groups of Yanomama females (p < 0.001). In the expeditionary control subjects, plasma renin activity was within the normal range. Samples for plasma renin activity were not obtained during studies of the Guaymi Indians.

Discussion

The existence of cultures that have no access to salt is well documented.¹²⁻²¹ However, the present study provides the first observations of the adjustments of sodium-related hormones in response to the stresses imposed upon sodium homeostasis by pregnancy and extended lactation in women existing in a “no-salt” culture. As in our prior study, the nature of the field conditions prevented some of the precision desired for studies focused upon sodium balance. Neither sodium intake nor loss from nonurinary routes could be measured. The numbers available to study were severely restricted by the small size of the remote Yanomama village in which the work was performed and the limited cooperation of the villagers. Nevertheless, the estimated 24-hour excretion of sodium in the male Yanomama, about 1 mEq/24 hours, is reassuringly similar to quantities found in our prior study.³⁰ The absolute concentrations of sodium in the spot urine samples of these subjects approximated those determined in the 24-hour collections of urine. Thus, it seems reasonable to assume that concentrations determined in the spot samples accurately reflect the status of homeostatic processes for conservation of sodium. In the Yanomama culture, the diet is essentially the same for males and females. We believe the small quantities of sodium (approximating 1 mEq/l) in the urine samples of the female Yanomama reflect their lifelong paucity of dietary sodium. Similarly, it seems reasonable that the concentrations of sodium in the urine of the Guaymi females accurately reflect the observed use of salt in their diet, yielding similar Na/K ratios to the Guaymi males in whom 24-hour urine samples contained an average of 66.8 mEq of sodium. Thus, within the recognized limitations of the study protocol, the collected data describe adjustments of the renin-aldosterone system to stresses imposed upon sodium balance occasioned by pregnancy and prolonged lactation in two cultures: “no-salt” and “salt-plentiful.”

The most impressive findings of the study were the exceedingly high concentrations of aldosterone in the urine of the pregnant women of the Yanomama tribe (table 2). These were associated with plasma renin activity and serum aldosterone concentrations higher than in any of the other groups of subjects. Although values for serum and urinary concentrations of aldosterone were increased in pregnant women of the Guaymi tribe compared with other subjects, the concentrations of urinary aldosterone were significantly lower (p < 0.001) than values in the pregnant subjects existing in a “no-salt” culture. Not unexpectedly, in view of our prior observations,¹⁰ values for plasma renin activity and concentrations of serum and urinary aldosterone were higher in the males and nonpregnant females of the Yanomama tribe compared with control subjects.

In contrast to the apparent marked augmentation of the renin-angiotensin-aldosterone system reflected in the hormonal values found in the pregnant Yanomama, the stress to sodium homeostasis caused by prolonged lactation (3 months to 3 years) could not be distinguished by values for renin and aldosterone from the stress imposed by lifelong existence with a low sodium intake as reflected in levels of these hormones in the nonlactating women. However, other factors, both major and minor, contribute to sodium homeostasis in the circumstance of a paucity of dietary sodium. These include the possibilities of an heightened appetite for substances of relatively greater salinity,²⁷,²⁸ or, temporarily, mobilization of skeletal sodium.²⁹ We have no information about these factors.

Mothers and infants in this culture appear healthy, with no evident disadvantage from their dietary pattern. It is pertinent that the Yanomama Indians are not unique. The existence of other groups²⁰⁻²⁶ apparently surviving and thriving in the absence of sources of mineral salt or substances of high salinity suggests a widespread human ability to adapt to an environment characterized by a deficiency of sodium salts,³⁰,³¹ an adaptation stemming from the predominantly vegetarian diet of man’s arboreal primate ancestors.³² For a nomadic pattern of life, the ability to maintain sodium homeostasis in a sodium-poor environment with irregular dietary additions of that ion would be a distinct survival advantage, particularly during the stresses of pregnancy and prolonged lactation. The present observations provide some insight into the physiologic adaptations resulting in successful homeostasis for sodium in a sodium deficient environment. The data may have implications for understanding basic dietary requirements for sodium during pregnancy and subsequent lactation in contemporary societies.

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References


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