SALT-SENSITIVE HYPERTENSION is influenced by genetic background. The two rat strains developed by Dahl (8), with blood pressure that is either salt sensitive (Dahl-S) or salt resistant (Dahl-R), are a classic example in rodents. The demonstration of salt-sensitive hypertension within substrains of spontaneously hypertensive rats (SHR) (14) may indicate that the phenomenon can be controlled by a few genes. Considerable evidence indicates that the kidneys have a prominent role in mediating either the primary hypertension or the salt sensitivity of the hypertension. This finding may be of use in future studies directed at identifying genotypes associated with salt-dependent hypertension.

METHODS

Male animals of the Dahl-S strain, purchased from Harlan Sprague Dawley, and SHR from the La Jolla colony, SHR L-J, were maintained in the animal care facility at the University of California, San Diego (UCSD). All protocols and procedures were approved by the UCSD Animal Subjects Committee. Within each study, animals were of the same strain and age and, in addition, were matched by weight into control and experimental groups.

Sodium intake was varied by offering ad libitum access to one of two diets for 4 wk, beginning at 6 wk of age. The 1% NaCl diet (Teklad no. TD90220) contained 0.39% sodium, 0.72% potassium, 0.66% chloride, 0.15% magnesium, and the 8% NaCl diet (Teklad no. TD92023) contained 3.15% sodium, 0.71% potassium, 4.90% chloride, 0.86% calcium, and 0.14% magnesium.

The inhibitor of nitric oxide synthase, N\textsuperscript{G}-nitro-L-arginine (L-NNA), 50 mg/l, was dissolved in distilled water. At 15 wk of age, SHR L-NNA animals had free access to the drinking solution for the next 7 days, whereas age-matched control SHR animals ingested distilled water ad libitum.

Blood pressure was measured by indwelling arterial catheters, which were placed after 3 wk on the assigned diet (or 2 days before starting ingestion of L-NNA) using methodology described in detail previously (10). The reported mean arterial pressures were obtained the day or two before death at the end of the experimental period. Arterial blood, sampled via the indwelling catheter on the day of death, was analyzed by ion-selective electrodes for sodium, potassium, ionized calcium, and ionized magnesium. Plasma was analyzed for
chimrane using a commercially available kit (Sigma, St. Louis, MO).

Renal TZR density was determined by saturation analysis using the binding of \(^{3}H\)metolazone to renal membranes, as previously described in detail (4): whole kidneys were homogenized in 10 ml ice-cold 50 mM Tris-PO\(_4\) buffer, pH 7.4, and membranes were prepared by centrifuging them for 5 min at 600 \(g\) and centrifuging the resulting supernatant two times at 45,000 \(g\) for 20 min. The final pellet was suspended in 10 ml buffer and diluted to achieve a final concentration of 0.8–1.0 mg protein/ml in the binding assay. Binding of \(^{3}H\)metolazone to each membrane preparation was determined in duplicate at six concentrations of \(^{3}H\)metolazone ranging from 0.313 to 10 nM. Specific binding of \(^{3}H\)metolazone, defined by displacement with 10\(^{-4}\) M hydroflumethiazide, was analyzed by the Scatchard equation to calculate the density of the binding using the EBDA program of McPherson (12). Protein was assayed by the Bradford Coomassie blue method (6), with bovine gamma globulin as the standard. Binding maximum is reported as picomoles of binding sites per milligram of membrane protein.

Statistical analyses were conducted with the StatView program (Abacus Concepts, Berkeley, CA) using Student’s unpaired t-test. Values are expressed as means ± SE.

RESULTS

Dietary NaCl in Dahl-S hypertensive rats. Mean arterial blood pressure in the Dahl-S animals ingesting 1% NaCl (145 ± 1.33 mmHg) was significantly (\(P<0.0001\)) less than that in rats ingesting 8% NaCl (209 ± 8.93 mmHg) (Fig. 1). The plasma concentration of chloride was significantly higher (\(P<0.001\)) in the 8% NaCl group (100.2 ± 0.458 mmol/l) than in the 1% NaCl group (97.1 ± 0.474 mmol/l). The animals ingesting 8% NaCl did not differ from the 1% NaCl animals with respect to final body weight or the plasma concentrations of sodium, potassium, ionized calcium, and ionized magnesium. Single kidney weight in the 8% NaCl group (0.554 ± 0.016 g/100 g body wt) was significantly (\(P<0.0001\)) greater than in the 1% NaCl group (0.393 ± 0.010 g/100 g body wt). However, renal TZR density was not altered by dietary NaCl intake (1% = 1.01 ± 0.057 pmol/mg renal membrane protein, 8% = 1.09 ± 0.031 pmol/mg renal membrane protein; \(P\) not significant) (Fig. 2).

Dietary NaCl in SHR. Mean arterial blood pressure in the SHRJ animals ingesting 1% NaCl (137 ± 5.08 mmHg) was significantly (\(P<0.0001\)) less than in those ingesting 8% NaCl (202 ± 9.07 mmHg) (Fig. 1). The plasma concentration of ionized calcium was significantly lower (\(P<0.02\)) in the 8% NaCl group (1.08 ± 0.025 mmol/l) than in the 1% NaCl group (1.16 ± 0.013 mmol/l). The animals ingesting 8% NaCl did not differ from the 1% NaCl animals with respect to final body weight or the plasma concentrations of sodium, potassium, ionized calcium, and ionized magnesium. Single kidney weight in the 8% NaCl group (0.554 ± 0.016 g/100 g body wt) was significantly (\(P<0.0001\)) greater than in the 1% NaCl group (0.393 ± 0.010 g/100 g body wt). However, renal TZR density was not altered by dietary NaCl intake (1% = 1.01 ± 0.057 pmol/mg renal membrane protein, 8% = 1.09 ± 0.031 pmol/mg renal membrane protein; \(P\) not significant) (Fig. 2).

### Table 1. Values in SHR after L-NNA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>L-NNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Renal thiazide receptor</td>
<td>0.923 ± 0.058</td>
<td>1.08 ± 0.046*</td>
</tr>
<tr>
<td>Sodium</td>
<td>145.9 ± 0.261</td>
<td>143.0 ± 0.824†</td>
</tr>
<tr>
<td>Potassium</td>
<td>3.95 ± 0.063</td>
<td>4.43 ± 0.152†</td>
</tr>
<tr>
<td>Chloride</td>
<td>99.0 ± 0.425</td>
<td>95.9 ± 1.21†</td>
</tr>
<tr>
<td>Ionized calcium</td>
<td>1.19 ± 0.012</td>
<td>1.17 ± 0.023</td>
</tr>
</tbody>
</table>

Values are means ± SE in mmol/l except N\(^{6}\)-nitro-L-arginine (L-NNA) group renal thiazide receptor, in pmol/mg protein. SHR, spontaneously hypertensive rat. *\(P = 0.0513\), †\(P < 0.05\) vs. control.
sium, chloride, and ionized magnesium. Single kidney weight in the 8% NaCl group (0.517 ± 0.018 g/100 g body wt) was significantly (P = 0.0001) greater than in the 1% NaCl group (0.400 ± 0.007 g/100 g body wt). In contrast, renal TZR density was decreased by increasing dietary NaCl intake (1% = 0.803 ± 0.22 pmol/mg protein, 8% = 0.531 ± 0.056 pmol/mg protein; P = 0.0012) (Fig. 2).

Response to inhibition of nitric oxide synthase in SHR. Inhibition of nitric oxide synthase by administration of L-NNA for 7 days increased mean arterial blood pressure in SHR to 233 ± 3.50 mmHg (n = 6) versus 181 ± 2.71 mmHg (n = 7; P < 0.0001) in the control SHR animals. Plasma sodium and chloride concentrations were slightly lower, whereas the plasma potassium concentration was significantly higher in the L-NNA group (Table 1). The 17% increase in renal TZR associated with the increase in blood pressure produced in SHR by L-NNA, which represented a marginal level of statistical significance (P = 0.0513; Table 1), contrasts with the 34% decrease in TZR associated with the increase in blood pressure produced in SHR by the 8% NaCl diet (Fig. 2).

DISCUSSION

The renal response to ingestion of a diet containing 8% NaCl in normotensive rats (Sprague-Dawley and WKY strains) in a prior study did not involve a change in the renal density of TZR (9). Concurrently, Moreno et al. (13) used different methodology to arrive at a similar conclusion. Our current study tested for derangements in TZR in salt-loaded, salt-sensitive hypertensive animals. These studies were based on the knowledge that hypertensive SHR have greater renal TZR density than do WKY (3) and the findings that the renal adjustments to excretion of salt are abnormal in salt-sensitive hypertension (16). Dahl-S animals developed severe hypertension (209 mmHg) with, as in normotensive strains, no change in renal TZR density (Figs. 1 and 2). In contrast, salt-induced hypertension of similar magnitude (202 mmHg) in SHR was accompanied by a 34% decrease in renal TZR (Figs. 1 and 2). Salt loading increased renal weight in both Dahl and SHR strains to a similar extent (single kidney weights per 100 g body wt were not significantly different between Dahl and SHR on either salt intake). Thus the decrease in TZR density in SHR versus Dahl cannot be attributed to differential changes in overall renal size. A decrease in TZR of 34%, if expressed as reduced reabsorption of NaCl at its locus in the distal convoluted tubule (5, 15), would facilitate urinary excretion of the excess dietary NaCl in SHR. Following this line of reasoning leads to the presumption that normotensive rat strains and the Dahl-S strain, when presented with a large dietary NaCl load, decrease reabsorption of NaCl predominantly in nephron segments other than the distal convoluted tubule. In this regard, it is of interest to note that thiazide treatment 1) prevents salt-dependent hypertension in Dahl-S animals (11, 18, 19) but 2) does not prevent salt-dependent (4% dietary NaCl) strokes in stroke-prone SHR (17). Although studies on the efficacy of thiazides on salt-accelerated hypertension in non-stroke-prone SHR are not available, thiazide diuretic treatment of SHR on normal diets has not yielded consistent lowering of blood pressure (reviewed in Ref. 2).

Blood pressure also increased markedly in SHR animals ingesting L-NNA, an inhibitor of nitric oxide synthase. The absolute level of mean arterial blood pressure (233 ± 3.50 mmHg) slightly exceeded that measured in SHR ingesting high salt (202 ± 9.07, P < 0.01) in the prior study, perhaps due to the older age of the animals used in the L-NNA study. However, the increase in blood pressure with L-NNA in SHR was not accompanied by a decrease in renal TZR. This finding of a lack of effect of arterial pressure on renal TZR is similar to our prior finding that renal perfusion pressure did not alter TZR in animals with two-kidney, one-clip hypertension (3). We propose that the decrease in renal TZR found in NaCl-loaded SHR is not secondary to a nonspecific effect produced by any increase in arterial pressure.

Perspectives

The renal response of salt-resistant normotensive [Sprague-Dawley and WKY in our prior study (9), Wistar in another study (13)] and salt-sensitive Dahl-S rat strains to high NaCl (8% NaCl) intake does not include a decrease in renal TZR, despite the differing effects of the salt on blood pressure. In contrast, renal TZR in the SHR strain is decreased 34% by NaCl-aggravated hypertension. A similar elevation of blood pressure in SHR produced by inhibition of nitric oxide synthase does not decrease renal TZR. These data provide evidence that renal responses to salt loading are not uniform and are therefore under genetic control that can be independent of renal responses to increased renal perfusion pressure. This observation 1) indicates that caution is needed when interpreting effects of dietary NaCl across strains of animals and 2) may be of use in future studies directed at identifying genotypes associated with salt-dependent hypertension.

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