

# Improved Arterial Distensibility in Normotensive Subjects on a Low Salt Diet

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Arterial pulse wave velocity (PWV), a noninvasive index of arterial distensibility, was measured in 57 normotensive subjects who followed a voluntary low salt diet for a period ranging from 8 months to 5 years (mean, 24.8 months). Subjects who followed a regular diet were matched for age and mean arterial pressure with the low salt (LS) sample and were used as controls (C). For both samples, subjects were divided into three age groups: Group 1 (aged 2 to 19 years,  $n = 16$ ), Group 2 (29 to 44 years,  $n = 26$ ), and Group 3 (45 to 66 years,  $n = 15$ ). There was a marked increase in aortic PWV with age in the control sample but not in the LS sample. There was no significant difference in aortic PWV for Group 1, but in Groups 2 and 3, the LS subjects showed a decrease of 21.8% and 22.7%, respectively, compared to C subjects. Aortic PWV (cm/sec) was: Group 1: C = 581 (SE 44), LS = 614 (SE 31); Group 2: C = 942 (SE 46); LS = 737 (SE 27) ( $p < 0.001$ ); Group 3: C = 958 (SE 77), LS = 741 (SE 25) ( $p < 0.05$ ). Arm and leg PWV were also significantly lower in the older age groups. These findings suggest that normotensive adult subjects who follow a low salt diet (mean intake, 44 mmol Na/24 hours) have reduced arterial stiffness and that the effect is independent of blood pressure. This is *prima facie* evidence that reduced salt intake has a beneficial effect in improving distensibility of the central aorta and large peripheral arteries, which is independent of its antihypertensive action. (Arteriosclerosis 6:166–169, March/April 1986)

**A**ging is associated with increased arterial stiffness, increased arterial pressure, and a higher prevalence of hypertension. All are usually regarded as normal aging phenomena, and it is usually considered appropriate to adjust the normal range of arterial pressure for age.<sup>1</sup> However, it is well known that in unacculturated societies with low dietary salt intake, arterial pressure rises to a lesser degree with increasing age, and prevalence of hypertension is markedly less than in Western societies with regular salt intake.<sup>2–6</sup> Recent studies<sup>7,8</sup> have shown that arterial stiffness (measured as aortic pulse wave velocity) is also dependent on dietary salt intake and that the relationship between arterial stiffness and salt intake is independent of, and additional to, the relationship between stiffness and mean arterial pressure. Such findings raise the question as to whether arterial stiffness can be modified by change in salt intake, independently of any effect of salt intake alter-

ation on blood pressure. This question was addressed in the present study where arterial pulse wave velocity was determined in two urban Australian population samples, one a group of normotensive subjects on a voluntary diet of unsalted foods, and the other a reference population on a regular diet, matched for age and arterial pressure.

## Methods

The low salt (LS) group was composed of 57 subjects (27 males and 30 females) who had participated in previous trials conducted at the Low Sodium Clinic of the Woden Valley Hospital in Canberra.<sup>9,10</sup> These subjects (41 adults with 16 of their children) were all normotensive (systolic pressure <160 mm Hg and diastolic pressure <95 mm Hg) and had elected to continue voluntarily on a diet of unsalted foods. Adherence to this diet was determined by scored response to a pretested diet questionnaire and by determination of sodium and potassium concentration in a morning urine specimen collected 1 to 10 days before the test. A previous study in the same trial population (unpublished observations) had established that the potassium/sodium (K/Na) ratio from a single early morning urinary specimen was a reliable estimate of the true 24-hour K/Na ratio (correlation coefficient 0.89) and that this best could be used as a reliable index of compliance with a salt-free diet.

Arterial pulse wave velocity (PWV) was measured as described previously.<sup>7,8</sup> Subjects were examined in a well-ventilated, evenly heated room. After they had rested 5 to 10 minutes, supine blood pressure was measured to the nearest 2 mm Hg in the right arm with a mercury sphygmo-

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manometer by use of the disappearance of Korotkoff sounds (phase 5) for diastolic pressure (DBP). Mean arterial pressure (MAP) was calculated as  $DBP + 1/3$  pulse pressure. PWV was measured in the aorta, right arm, and right leg. The PWV was determined by detection of the arterial flow velocity pulse at two different locations. Two identical 10 Mhz Doppler transducers (Parks 802) were used to detect the pulse between the aortic arch and the femoral artery (Aortic PWV), between the femoral and post-tibial arteries (Leg PWV), and between the brachial and radial arteries (Arm PWV). Transit time (dt) was obtained by electronically delaying the image of the proximal pulse on a visual display unit, so that the early rising limbs of both proximal and distal waves were superimposed. The delay time was read off directly from a digital display. The distance traveled by the pulse wave (dx) was taken as the linear distance between the surface markings of the recording sites. The PWV was calculated as  $PWV = dx/dt$  and expressed in cm/sec. A second supine blood pressure measurement was taken in the arm after the PWV measurement. The average MAP was calculated as the mean of the MAP obtained at the start and finish of the procedure. Height, weight, and additional dietary information were obtained at the end of the procedure, which lasted 15 to 20 minutes.

The 57 subjects who reduced their salt intake were matched for age and MAP with subjects (51 males and six females) from a previous study of PWV in self-selected entrants to the Medichcek Referral Centre, a multiphasic screening service in Sydney.<sup>11</sup> Subjects from this study were normal healthy individuals from a cross section of the urban Sydney population who followed a regular Australian diet. The age distribution was such that the subjects fell into two groups: a predominantly young group (age range, 2 to 19 years) and an older group (age range, 29 to 66 years). To obtain an appropriate balance between age range and number of subjects, the second group was subdivided further into a middle age range (29 to 44 years) and an older age range (45 to 66 years).

Statistical analysis was performed by using a two-sample Student's *t* test for calculation of the level of significance for differences between control and treated samples.

Ethical approval for the original dietary intervention was given by the Ethics Committee of the Australian Capital

Territory Health Commission, and informed consent was obtained from all subjects in the study.

## Results

The age distribution was 2 to 19 years (mean, 10.4 years; *n* = 16) in Group 1, 29 to 44 years (mean, 39.8 years; *n* = 26) in Group 2, and 45 to 66 years (mean, 54.5 years; *n* = 15) in Group 3. Low salt intake had been in effect for a mean of 24.8 months (SE 2.5 months; range, 8 months to 5 years). Their mean molar K/Na ratio in early morning urine samples was 2.1 (SE 1.1, range, 0.21 to 16.2), corresponding to an estimated mean sodium excretion rate of 44 mmol/24 hours. Adherence to the low salt diet was confirmed by the positive and statistically significant correlation obtained between the scored response of the pretested diet questionnaire and sodium excretion levels ( $r = 0.31$ ;  $p < 0.05$ ).

Table 1 shows age, weight, height, SBP, DBP, and MAP for the three LS age groups compared with the matched controls, together with K/Na ratios, estimated 24-hour sodium excretion rates, and average duration of salt restriction. While the average duration for Group 1 (youngest subjects) was over 2 years (mean, 26.2 months; SE 5.4 months), the questionnaire indicated that they were avoiding salt less strictly than the adults. This was confirmed by the urine results, the average estimated sodium excretion rate being 68 mmol/24 hours. No data for urine sodium excretion were obtained for control subjects, but the estimated range of sodium intake of Australian adults on a regular diet is 130 to over 200 mmol/day.<sup>12</sup>

The PWV in LS subjects was generally lower than in controls (Figure 1), with the difference varying between age groups and arterial sites. In the youngest subjects (Group 1), no significant difference was found in the aortic or arm PWV, but significantly lower leg PWV (difference of 11.2%,  $p < 0.05$ ) was found in LS subjects. Group 2 showed significantly lower PWV for LS subjects in all three locations (aorta: 21.8%,  $p < 0.001$ ; arm: 10.7%,  $p < 0.05$ ; leg: 13.3%,  $p < 0.05$ ). Group 3 showed significantly lower PWV for LS subjects in the aorta and leg (aorta: 22.7%,  $p < 0.05$ ; leg: 22.3%,  $p < 0.05$ ).

There was a significant difference in mean body weight between LS and control subjects in Group 2, but not in Groups 1 and 3 (Table 1). Group 2 had a different sex

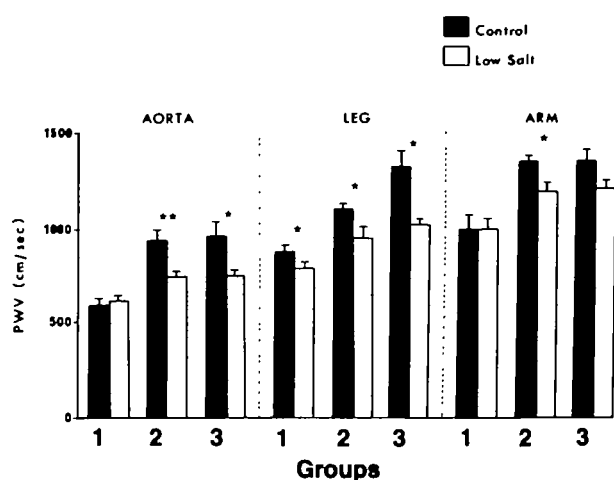
**Table 1. Distribution of Low Salt and Control Groups by Age, Weight, Blood Pressure, Urinary Electrolyte Excretion, and Duration of Dietary Change**

Group	Age (yrs)		Weight (kg)		Height (cm)		SBP (mm Hg)		DBP (mm Hg)		MAP (mm Hg)		Time (mos)		Molar K/Na		Na (mmol/24 hr) Average*
	Mean	2 SE	Mean	2 SE	Mean	2 SE	Mean	2 SE	Mean	2 SE	Mean	2 SE	Mean	2 SE	Mean	2 SE	
1 ( <i>n</i> = 16)																	
Control	10.8	1.9	37.3	8.6	140.2	8.5	112.1	5.7	62.1	3.8	78.9	4.1					†
Low salt	10.4	2.5	35.1	8.7	137.9	13.8	110.4	6.6	62.1	4.9	78.1	4.4	26.2	10.8	1.11	.58	68
2 ( <i>n</i> = 26)																	
Control	39.4	1.7	81.1	5.3	174.9	2.7	124.4	5.0	78.7	4.2	93.9	4.1					†
Low salt	39.8	1.6	63.8	3.9	167.6	2.9	123.7	4.9	80.6	3.3	94.6	3.6	18.9	5.4	1.85	.42	41
3 ( <i>n</i> = 15)																	
Control	52.2	3.5	78.2	4.2	172.6	3.3	127.8	6.0	80.2	3.3	96.1	3.4					†
Low salt	54.5	4.2	70.7	4.6	173.1	4.4	129.6	7.4	84.1	2.5	99.3	3.1	33.4	16.4	3.42	2.67	22

SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure. Sex distribution: Control Group 1: 10 males, six females; Control Groups 2 and 3: all males. Low salt Group 1: Six males, 10 females; Low Salt Group 2: 11 males, 15 females; Low Salt Group 3: 10 males, five females.

\*The average value of Na/24 hr was estimated from the mean molar K/Na ratio determined from an early morning urine specimen.

†The range of sodium intake for Australian subjects on a regular diet is estimated at 130 to over 200 mmol/day.



**Figure 1.** Pulse wave velocity (PWV) at different arterial sites and in different age groups: Group 1 = 2 to 19 years; Group 2 = 29 to 44 years; Group 3 = 45 to 66 years. \* =  $p < 0.05$ ; \*\* =  $p < 0.001$ ; bars = 2 SEM.

distribution, with a larger proportion of females in the LS sample. Female subjects in the LS sample of Group 2 had a mean body weight 14% less than male subjects in the same group. However, while PWV increased with age in both males and females, no significant difference was found in the slope and intercept of regression equations for the aortic, leg, or arm PWV of male and female subjects in the low salt group: males,  $y = 3.76x + 602$ ,  $r = 0.42$ ,  $p < 0.05$ ; females,  $y = 3.17x + 561$ ,  $r = 0.52$ ,  $p < 0.05$ . ( $x$  = age in years,  $y$  = aortic PWV in cm/sec). Because of its close relationship to total arterial compliance,<sup>7,8</sup> aortic PWV is considered to be the most physiologically important. Furthermore, no significant positive correlation was found between PWV and body weight independent of age and arterial pressure for the low salt group.

### Discussion

The major finding reported here is of lower PWV in normotensive urban Australian subjects who had avoided salt, compared with a reference group matched for age and arterial pressure. This suggests an association between salt intake and arterial stiffness that is independent of blood pressure. This finding is similar to that in an earlier study of two Chinese populations with different salt intakes.<sup>7,8</sup> These Chinese populations, however, had differed in their salt intake throughout life, whereas the Australians had differed for a comparatively short period. These results indicate not only that increased arterial stiffness with age is related to salt intake, but that it is also reversible with restriction of dietary salt. Other studies have reported an increase in forearm volume arterial distensibility of hypertensive subjects after only 1 month of treatment with thiazide diuretics.<sup>13</sup> Although this may have been due to a reduction in blood pressure caused by the diuretics, it has been shown that reduction in brachial artery compliance obtained with isotonic saline infusion is due to mechanisms other than changes in blood pressure.<sup>14</sup>

Findings of the type described in this study have never been reported before. While the findings are consistent with data from the Chinese studies, it is surprising that a relatively short period of sodium restriction may modify the

physical behavior of the arterial wall. The findings reported here are from a cross-sectional study and should be confirmed by a longitudinal study where PWV can be measured sequentially in individual subjects before and throughout a period of sodium restriction. These results suggest, however, that the period of observation will not need to be a whole lifetime, but only a few years, or possibly even months.

In the second age group (Group 2), the low salt and control groups showed a marked difference in body weight. A small weight loss is inevitable in a treatment group that eliminates salted foods from the diet,<sup>9</sup> but the substantial difference seen here was due mainly to the larger proportion of females in the low salt group. Subjects were not matched for sex because previous PWV studies had detected no sex difference.<sup>7,8,11</sup> Since a similar difference in aortic PWV was found in Group 3 (21.8% compared to 22.7%) in which the difference in body weight was considerably smaller (Table 1), it is unlikely that body weight per se contributes significantly to the lower PWV in the low salt group. Furthermore, no significant correlation was found between PWV and body weight independent of age and arterial pressure within each group.

The cause of the arterial stiffness that increases PWV is unknown, and no obvious mechanism would connect it with salt intake. The effect of sodium on the action of the sympathetic nervous system has been shown to affect arterial compliance.<sup>14</sup> Other studies have shown that hypertensives and some of their close relatives have a demonstrable defect in sodium transport across cell membranes,<sup>15,16</sup> supporting the hypothesis that a circulating natriuretic factor can raise blood pressure by peripheral vasoconstriction due to altered intracellular electrolytes in vascular smooth muscle.<sup>17,18</sup> Since smooth muscle tone is known to affect arterial elasticity,<sup>19</sup> this mechanism may explain the findings reported here. It may also explain the increased compliance of large arteries observed with vasodilators such as nitroglycerine, calcium antagonists, and converting enzyme inhibitors.<sup>20</sup> If some such mechanism is related to stiffness in large arteries, however, it is apparently not confined to hypertensive individuals, as the present study compared two groups matched for blood pressure within the normal range, many with no family history of hypertension.

Longitudinal studies are currently being planned in Canberra and in Geelong, Victoria.

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Index Terms: arterial distensibility • dietary salt intake • pulse wave velocity