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# Blood Pressure and Salt Intake in High Altitude Bolivian Aymara

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ABSTRACT

Native people at the Andean high altitudes are believed to have low systemic blood pressure, a low prevalence of hypertension and a lower risk of coronary heart disease than people at sea level. Some recent studies in other areas at high altitudes have pointed to an increased prevalence of systemic hypertension, making this issue controversial. However, very little information is available to explain the nature of low blood pressure in high altitude natives or the phenomenon of hypertension. Our comparative studies on populations in the Bolivian Andes (4000 m above sea level) indicated no significant differences in blood pressure with changes in altitude. In high-altitude subjects, mean amounts of urinary excretion of both sodium (Na) and potassium (K) were higher than expected and were more than twice as high as those in low-altitude subjects; the mean daily urinary Na excretion was about 260 mmol/day (15 g of NaCl) at high altitudes. Multiple regression analysis indicated that age and arm circumference were the two major determinants of blood pressure, after the other variables were controlled for; no independent relations of body mass index, body fat, or urinary excretion of Na and K with blood pressure were detected. Multiple regression analysis also indicated that altitude was a significant independent variable for increased diastolic blood pressure and for decreased pulse pressure. The hypoxic environment and high levels of salt and K consumption may have negated altitude's effects on blood pressure. These and other physiological roles of salt and mineral consumption in high-altitude dwellers warrant further study.

## INTRODUCTION

Populations in the Andean Altiplano have been reported to have a low prevalence or complete absence of hypertension and comparatively low blood pressure levels (Baker, 1969; Buck et al., 1968; Marticorena et al., 1969; Ruiz and Peñaloza, 1977; Heath and Williams, 1981). This tendency has been observed in areas other than Andean high altitudes (Appleton, 1967). However, a reverse trend is also reported, for example in a study of the Peruvian Quechua population (Makela et al., 1978), in a study of Ethiopian highland groups (3000 m above sea level: Harrison et al., 1969), or in a study of in Colorado in the western USA (Moore et al., 1982). In Tibetans, no significant inverse association between the prevalence of hypertension and altitudes (2500–5000 m) was observed, but the prevalence of hypertension was higher than in Hans who migrated from lower altitudes and lived at high altitudes (Sun, 1986). A study of Himalayan communities compared blood pressures between high-altitude (3000 m) subjects and subjects who lived on plains at lower altitudes and concluded that no possible effect of high altitude on blood pressure was apparent (Dasgupta et al., 1982). Thus, blood pressure in people at high altitudes remains a matter of controversy.

While a positive relation between the prevalence of hypertension/or an increased blood pressure and salt intake, obesity and aging has been established in epidemiological studies, only a few studies are available which examined age and body composition in comparing blood pressure between high and low-altitude populations. Virtually no information is available with respect to salt consumption, or sodium (Na) and potassium (K) consumption, and

other nutritional variables of high altitude natives.

Viewing these findings in the light of previous studies, the present study had two objectives. Using the data on anthropometric measurements and urinary excretion of Na and K in casual urine in subjects of the Bolivian Altiplano and their counterparts at low altitude, we examined: (1) whether or not the blood pressure of the high-altitude natives is lower than that of their low-altitude counterparts, and (2) whether it was possible to identify factors which are related to blood pressure. The present report is based on studies in 1988 and 1989 which were conducted as part of an ongoing research project on Comparative Human Ecology of Resource and Environment Use, in Bolivian communities of different altitudes (Kashiwazaki, unpublished manuscript).

## SUBJECTS AND METHODS

### Subjects

As indicated in Table 1, a total of 614 subjects participated in the study. The subjects in the high-altitude groups were those from two typical rural communities of the Andean Altiplano. These communities are located at an approximate elevation of 4000–4100 m above sea level and in every sense they are typical rural Aymara communities. Details of the community are presented elsewhere (Kim et al., 1991). The subjects from low altitudes were from the Alto Beni, subtropical Amazonian lowland colonies with a history of settlement as long as 40 years. The low-altitude subjects included migrants from Altiplano and low-altitude natives. Aymara and Quechua are the major groups of migrants from Altiplano in this area.

TABLE 1

Subjects of the present study

| Age groups | Altiplano | | Low Altitude | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| –9 | 7 | 4 | 72 | 69 |
| 10–19 | 35 | 24 | 36 | 40 |
| 20–29 | 9 | 12 | 24 | 25 |
| 30–39 | 17(1) | 15 | 21 | 30 |
| 40–49 | 11(1) | 20 | 21 | 21(1) |
| 50–59 | 11 | 13(2) | 12(3)* | 3(1) |
| 60–69 | 16(1) | 16(1)* | 8(1)* | 3 |
| 70–79 | 4 | 5(2)* | 6 | 1(1) |
| 80– | 1 | 2 | 0 | 0 |
| Total | 111 | 111 | 200 | 192 |

Numbers in parentheses are borderline hypertensive and hypertensive subjects.
*Includes one hypertensive subject.
Hypertensive: SBP ≥ 160 or DBP ≥ 95.
Borderline Hypertensive: SBP 141–159, DBP 91–94.

### Anthropometry and blood pressure

At the time of the house-to-house census survey, blood pressure in subjects 15 years of age and older was measured as a part of anthropometric measurements, using standard methods. Blood pressure readings were taken by a sphygmomanometer with the subject sitting at rest. Subjects were defined as hypertensive if they were found to have 160 mm Hg or higher systolic, or 95 mm Hg or higher diastolic blood pressure, or both. Borderline hypertension was indicated if subjects had a systolic pressure of 140–159 mm Hg or a diastolic pressure of 90–94 mm Hg. At the initial measurement, those found to have high blood pressure, both hypertensive and borderline hypertensive, were measured again after 10 minutes' rest. Since the subjects younger than 15 years have no data on blood pressure and on some anthropometric items, the results presented hereafter are those for adult subjects (20 years of age and over), unless otherwise specified.

### Urine samples

On a separate occasion, after completion of anthropometry, subjects were asked to submit single urine samples, preferably in mid-morning. About 10% of the subjects randomly selected were also asked to collect 24-h urine, the day before or the day after the collection of casual urine. The data on 24-h urine were used to check the validity of the casual urine data. Collected urine samples were measured for creatinine concentration with Jaffe's reaction (Creatinine-Color Test: Boehringer–Mannheim) as soon as possible. Then an aliquot containing about 30 ml from each sample was transferred to a polyethylene container, which was washed clean using nitrate acid and was kept free of metal contamination. The urine samples were kept in a cool place or in a refrigerator. These were frozen in La Paz, Bolivia, and subsequently sent to Japan for analysis. Analysis for Na and K concentrations was performed by AAS (Atomic Absorption Spectrometer, AA-845, Nippon Jarrel Ash, Kyoto). Using urine of known concentration for Na and K, accuracy and precision were checked daily, and proved to be acceptable; the within-day variations of measurements were less than 5% (CV).

Excretion of Na and K over 24 h was estimated from the concentration of Na and K per g creatinine in casual urine using expected creatinine excretion,

TABLE 2

Physical characteristics of the adult subjects

| | Male subjects | | | | | Female subjects | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Altiplano | | Lowland | | *t*-test | Altiplano | | Lowland | | *t*-test |
| | Mean | SD | Mean | SD | H vs. L | Mean | SD | Mean | SD | H vs. L |
| Age | 47.7 | 15.5 | 41.9 | 15.2 | a | 47.0 | 15.5 | 36.2 | 11.3 | b* |
| BMI | 23.5 | 2.5 | 23.6 | 2.6 | NS | 24.3 | 4.1 | 24.2 | 3.2 | NS |
| Mid-arm (cm) | 25.0 | 1.7 | 25.3 | 1.7 | NS | 23.4 | 2.6 | 23.9 | 2.7 | NS |
| LBM | 52.7 | 4.9 | 49.3 | 5.0 | b | 39.7 | 3.8 | 37.3 | 4.3 | b |
| Fat % | 13.2 | 4.6 | 16.9 | 5.5 | b | 25.0 | 6.3 | 29.0 | 5.6 | b |
| Ht (%) | 56.0 | 5.2 | 45.1 | 4.6 | b | 51.3 | 4.9 | 39.6 | 5.4 | b |
| Hb (g/dl) | 18.5 | 1.7 | 13.5 | 1.8 | b | 17.0 | 1.4 | 11.6 | 2.1 | b |
| SBP, mm Hg | 117.5 | 12.5 | 120.5 | 16.0 | NS | 112.9 | 14.9 | 111.9 | 14.1 | NS |
| DBP, mm Hg | 77.4 | 9.2 | 74.4 | 11.6 | NS | 72.7 | 11.2 | 68.2 | 9.2 | b |
| PP, mm Hg | 40.1 | 10.5 | 45.5 | 10.6 | b | 39.7 | 11.3 | 43.8 | 10.4 | a |

BMI: Body Mass Index. Mid-Arm: Upper arm circumference. LBM: Lean Body Mass estimated from skinfold thicknesses. Fat %: Calculated from estimated LBM. SBP: Systolic blood pressure. DBP: Diastolic blood pressure. PP: Pulse pressure.
a, b: Significance of difference by *t*-test between subjects of high and low altitudes; a, $p < 0.05$; b, $p < 0.01$ (*: Welch's test).

assuming the subjects were on *ad libitum* diet from estimated LBM: lean body mass (Forbes, 1987). LBM and fat % was estimated from skinfold thickness and body weight, using the equations of body density (Durnin and Womersley, 1974) and of LBM (Brozek et al., 1963). Correlations between the estimated 24-h excretion in casual urine and the excretion in the 24-h urine for Na were 0.477 ($n = 48$, $p < 0.01$), and $r = 0.410$ ($n = 48$, $p < 0.01$) for K.

The statistics used were the *t*-test for comparison of variables between low and high altitude subjects, Pearson's correlations and the stepwise procedure of multiple regression analysis. When the probabilities were less than 0.05 in the statistical test, the differences or correlations were regarded as statistically significant. All procedures were reviewed and approved by the Ethical Committee on Use of Human Subjects of the Faculty of Medicine, University of Tokyo.

## RESULTS

Prevalence of hypertension in subjects in the present study (20 years of age and over) were 1.3% (2/152) in the high-altitude group and 1.1% (2/175) in the low-altitude group. No significant difference between the two groups in the prevalence of hypertension was observed (Table 1). The prevalence of hypertension at high altitudes was similar to those in other Andean populations, 1.7% (3/181) in the Aymara of western Bolivia (Murillo et al., 1980). There was no inverse association between altitude and blood pressure, as was reported in the Peruvian Quechua (Buck et al., 1968).

Table 2 compares the physical characteristics of high and low-altitude subjects. In both male and female subjects at high altitudes, mean ages were somewhat older than in low-altitude subjects. Reflecting a physiological response to hypoxic high altitudes, subjects of the Altiplano had significantly greater concentrations of erythrocytes and hemoglobin (Ht and Hb). Although there were no apparently significant differences in body mass index (BMI) and upper arm circumference (mid-arm), the estimated fat % indicates that, in both sexes, the high-altitude subjects had significantly smaller body fat than low-altitude subjects. In both male and female subjects, no significant differences in systolic blood pressure (SBP) were observed between low and high-altitude groups. Diastolic blood pressure (DBP) in males did not differ significantly between low and high-altitude subjects, but DBP in female subjects at high altitudes was significantly higher than that in low-altitude subjects. An interesting piece of evidence is that the pulse pressure (PP) in both male and female subjects at high altitudes was significantly lower than in the low-altitude subjects.

Blood pressure by age and sex and by altitude is presented in Fig. 1. At high altitudes, SBP and DBP in both sexes increased with age. In subjects at low altitude, although subjects of 60 years and over appeared to show a reverse trend due to the small number of subjects, the general tendency was a positive relation between age and BP.

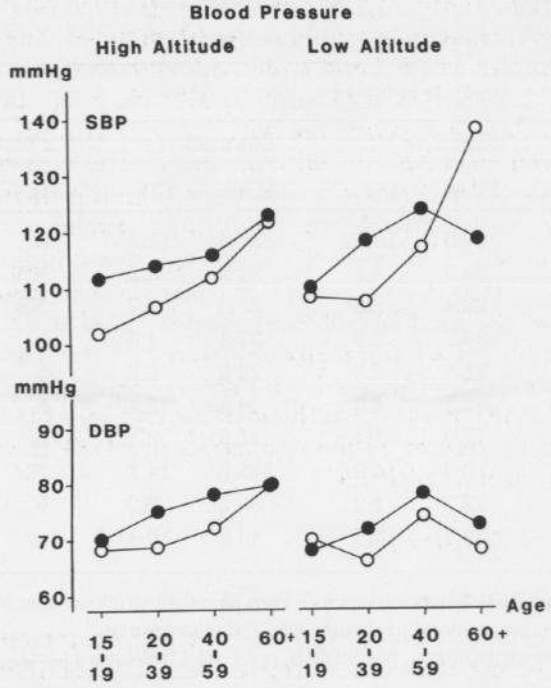


Fig. 1. Blood pressure by age, gender, and altitude. Filled circles, male; hollow circles, female.

Table 3 shows urinary Na and K excretion. The levels of both Na and K excretion in high-altitude subjects were more than twice as high as those in low-altitude subjects. The differences between the groups were statistically significant. The estimated 24-h excretions of Na were 282 mmol (equivalent to 16.5 g NaCl) in males and 248 mmol (equivalent to 14.5 g NaCl) in female subjects at high altitude, while it was 139 mmol (equivalent to 8.1 g NaCl) in males and 111 mmol (equivalent to 6.5 g NaCl) in female subjects at low altitude. However, due to a simultaneous high urinary K excretion in high-altitude subjects (male: 130 mmol, female: 118 mmol), no substantial differences in Na/K ratio were detected between the high and low-altitude groups.

Correlations of blood pressure (SBP, DBP and PP) with anthropometric data and urinary Na and K excretion are presented in Tables 4a and 4b. When the high and low-altitude subjects were combined (Table 4a), age correlated significantly with BP as expected. Upper arm circumference and BMI also correlated with BP. Other significant correlations detected were as follows: Ht and Hb with DBP; Na/K ratio with SBP; estimated 24-h Na excretion, estimated 24-h K excretion and Na/g creatinine excretion with DBP; and inverse correlations of estimated 24-h Na excretion, Na/g creatinine excretion, and K/g creatinine excretion with PP. In separate correlation analyses for high and low-altitude subjects, age and upper arm circumference were the common significant variables correlated with BP (Table 4b). In high-altitude subjects, upper arm circumference was the second significant variable, which correlated with BP, but none of the other variables, such as urinary Na and K excretion or BMI and fat % was correlated significantly. In low-altitude subjects, upper arm circumference showed the greatest correlation with BP, followed by age, BMI, estimated 24-h Na excretion, Na/K ratio, and Ht and Hb.

To determine the effects of these variables on BP while controlling for internal correlations, multiple regression analysis was performed using a stepwise

TABLE 3

Urinary electrolyte excretion of the adult subjects

| | Male subjects | | | | | Female Subjects | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Altiplano | | Lowland | | *t*-test | Altiplano | | Lowland | | *t*-test |
| | Mean | SD | Mean | SD | H vs. L | Mean | SD | Mean | SD | H vs. L |
| Na (g/g Cr) | 4.1 | 2.1 | 2.2 | 1.4 | b* | 4.5 | 2.2 | 2.3 | 1.6 | b* |
| K (g/g Cr) | 3.2 | 1.4 | 2.0 | 1.1 | b* | 3.8 | 2.0 | 2.2 | 1.0 | b* |
| Na(mmol/24 h) | 282.1 | 145.2 | 138.5 | 92.8 | b* | 247.9 | 107.3 | 111.4 | 73.7 | b* |
| K (mmol/24 h) | 129.7 | 57.0 | 73.9 | 41.1 | b* | 118.4 | 64.4 | 59.3 | 25.8 | b* |
| Na (g/24 h) | 6.5 | 3.3 | 3.2 | 2.1 | b* | 5.7 | 2.5 | 2.6 | 1.7 | b* |
| K (g/24 h) | 5.1 | 2.2 | 2.9 | 1.6 | b* | 4.6 | 2.5 | 2.3 | 1.0 | b* |
| Na/K (mol/mol) | 2.4 | 1.3 | 2.4 | 1.9 | NS# | 2.4 | 1.5 | 2.1 | 1.4 | NS |
| Na/K (g/g) | 1.4 | 0.8 | 1.4 | 1.1 | NS# | 1.4 | 0.9 | 1.2 | 0.8 | NS |

The values of 24-h excretion for Na and K are estimated using expected creatinine excretion for LBM (Forbes, 1987).
a, b: Significance of difference by *t*-test between subjects of high and low altitudes; a, $p < 0.05$; b, $p < 0.01$ (*: Welch's test).
#: Variance differs significantly ($p < 0.01$).

procedure. Table 5 summarizes the variables selected as significant in the analyses of two sets of variables (I and II). The complicated relations between BP and the variables were simplified. Urinary Na and K excretion, BMI, fat %, and gender were not selected as significant. Multiple regression of SBP included only two variables as significant: upper arm circumference and age together explained 25.3% of SBP variance. Regression of DBP included the same variables as SBP and added altitude as significant variable, indicating that high-altitude subjects had elevated DBP compared with the low-altitude subjects (added 2.8% explaining power). The same variables as for DBP were selected as significant in the case of PP. Altitude was the variable explaining the greatest variance of PP (7.5% explained): high-altitude subjects had lower PP than the low-altitude subjects. When the dummy variable of altitude was excluded from the stepwise procedure, hemoglobin concentration was selected as significant (set II of variables in Table 5). Hemoglobin appeared to have slightly greater influence in predicting DBP than did the variable 'altitude'.

TABLE 4a

Correlation of blood pressure with some selected variables: high- and low-altitude subjects combined

| Variables | SBP | DBP | PP |
|---|---|---|---|
| Age | 0.305b | 0.295b | 0.106 |
| Ht (%) | 0.091 | 0.205b | –0.082 |
| Hb (g/dl) | 0.076 | 0.231b | –0.136a |
| BMI | 0.245b | 0.217b | 0.135a |
| Arm circ. | 0.385b | 0.346b | 0.198b |
| Fat% | –0.042 | –0.112 | 0.053 |
| Na (mmol/24 h) | 0.058 | 0.194b | –0.105 |
| K (mmol/24 h) | –0.015 | 0.137a | –0.156b |
| Na (g/g Cr) | –0.003 | 0.139a | –0.147a |
| K (g/g Cr) | –0.082 | 0.042 | –0.169b |
| Na/K (mol/mol) | 0.129a | 0.084 | 0.105 |
| LN (Na/K) | 0.086 | 0.087 | 0.033 |

SBP: Systolic blood pressure. DPB: Diastolic blood pressure. PP: Pulse pressure.
a: $p < 0.05$, b: $p < 0.01$.
On Subjects 20 years of age and over.

## CONCLUSIONS

### Age and body composition

Age and arm circumference were the common and major variables explaining the variances of SBP and DBP in the high and low-altitude subjects. Studies on blood pressure have usually identified increasing blood pressure with increased age. In this respect, age-related increase of blood pressure in our high-altitude subjects may not be surprising. Exceptions that show no age-related elevation of BP are populations with a 'no-salt' culture or groups relatively unexposed to modern life (Lowenstein, 1961; Truswell et al., 1972; Oliver et al., 1975; Mancilha-Carvalho et al., 1989), as well as high-altitude Andean

TABLE 4b

Correlation of blood pressure with some selected variables in adult subjects (20 years of age and over)

| Variables | High-altitude subjects | | | Low-altitude subjects | | |
|---|---|---|---|---|---|---|
| | SBP | DBP | PP | SBP | DBP | PP |
| Age | 0.320b | 0.256b | 0.148 | 0.334b | 0.275b | 0.194a |
| Ht (%) | 0.071 | 0.043 | 0.072 | 0.243b | 0.210a | 0.113 |
| Hb (g/dl) | 0.133 | 0.102 | 0.082 | 0.220a | 0.224a | 0.049 |
| BMI | 0.161 | 0.078 | 0.137 | 0.333b | 0.369b | 0.144 |
| Arm circ. | 0.184a | 0.180a | 0.070 | 0.549b | 0.533b | 0.284b |
| Fat % | –0.117 | –0.143 | –0.023 | –0.019 | –0.029 | 0.010 |
| Na (mmol/24 h) | 0.047 | 0.094 | –0.023 | 0.231a | 0.197a | 0.116 |
| K (mmol/24 h) | 0.034 | 0.093 | –0.040 | 0.060 | 0.089 | –0.039 |
| Na-spt (g/g Cr) | –0.029 | 0.070 | –0.104 | 0.117 | 0.096 | 0.045 |
| K-spt (g/g Cr) | –0.021 | 0.023 | –0.057 | –0.106 | –0.078 | –0.116 |
| Na/K (mol/mol) | –0.001 | 0.015 | –0.004 | 0.231a | 0.131 | 0.221a |
| LN (Na/K) | 0.002 | 0.066 | –0.055 | 0.153 | 0.071 | 0.152 |

SBP: Systolic blood pressure. DBP: Diastolic blood pressure. PP: Pulse pressure.
a: $p < 0.05$, b: $p < 0.01$.

TABLE 5

Multiple regression analysis on adult subjects

| Independent variables | I Standardized partial regression coefficients | | | II Standardized partial regression coefficients | | |
|---|---|---|---|---|---|---|
| | Dependent variables | | | Dependent variables | | |
| | SBP | DBP | PP | SBP | DBP | PP |
| Age | 0.313b | 0.272b | 0.196b | 0.313b | 0.264b | 0.189b |
| Gender* | ns | ns | ns | ns | ns | ns |
| BMI | ns | ns | ns | ns | ns | ns |
| Arm-circ.# | 0.414b | 0.394b | 0.190b | 0.414b | 0.363b | 0.233b |
| Fat % | ns | ns | ns | ns | ns | ns |
| Urinary Na | ns | ns | ns | ns | ns | ns |
| Urinary K | ns | ns | ns | ns | ns | ns |
| Urinary Na/K | ns | ns | ns | ns | ns | ns |
| Altitude* | ns | 0.161b | –0.276b | – | – | – |
| Hb (g/dl) | – | – | – | ns | 0.204b | –0.209b |
| Ht (%) | – | – | – | ns | ns | ns |
| R2 | 0.253b | 0.237b | 0.145b | 0.253b | 0.249b | 0.114b |

*Dummy variables. Gender: male = 0, female = 1; altitude: high altitude = 1, low altitude = 0.
#: Upper arm circumference (cm).
I: Set of variables with exclusion of the hematological data.
II: Set of variables with inclusion of the hematological data instead of dummy variable "altitude".
Stepwise multiple regression analysis: the values are standardized partial regression coefficients of the variable selected as significant; ns: the corresponding variable was not selected as significant; b: $p < 0.01$.

natives. Heath and Williams (1981) refer to a study in which the trend of a rise in systemic blood pressure with age is not found in native Peruvian highlanders. In a study on the Aymara of western Bolivia, Murillo et al. (1980) also report no clear age dependence of blood pressure increase. However, as was reported on the Peruvian Quechua (Baker, 1969), the native Aymara at high altitude in the present study showed age-dependent increases in BP, suggesting that altitude or a hypoxic environment does not necessarily protect people against an elevation of systemic blood pressure in later life.

Body weight and BMI are the other most commonly observed variables that are strongly, independently and positively correlated with blood pressure in many studies (e.g., Khaw and Rose, 1982; Rose and Stamler, 1989). This relation is usually interpreted as a rise in BP with body fatness. Pearson's correlations in our subjects apparently indicated that both BMI and arm circumference were related to blood pressure. However, the multiple regression analysis controlling for other interacting variables showed a somewhat different picture with respect to the relations of these variables with blood pressure. Arm circumference was the only significant variable of body-build that correlated independently. BMI and fat % were not the independent variables correlated with the elevation of BP. This finding contradicts the hypothesis of an elevation of BP with body fatness, but agrees with some other studies (Pickering et al., 1954; Clegg et al., 1976). The physiological basis of this relation is not clear; however, as Clegg et al. (1976) speculated, arm circumference is to some extent dependent on the overall health status of the population and the statistical association with blood pressure may be a reflection of socio-economic status in the particular ecological situation. This may only apply to a population in which variations in blood pressure are within the normal range.

### Urinary Na and K excretion

Although our subjects were not found to have any consistent and independent correlations of urinary Na or K with blood pressure, a high sodium urinary excretion together with an exceptionally high potassium urinary excretion in high-altitude subjects needs further examination. The results of the present analysis indicate that sodium intake of high-altitude subjects was surprisingly higher than that of their low-altitude counterparts. Estimated Na intake from urinary excretion of high-altitude subjects (male: 282 mmol, female: 248 mmol) was somewhat higher than that estimated from our seven-day food

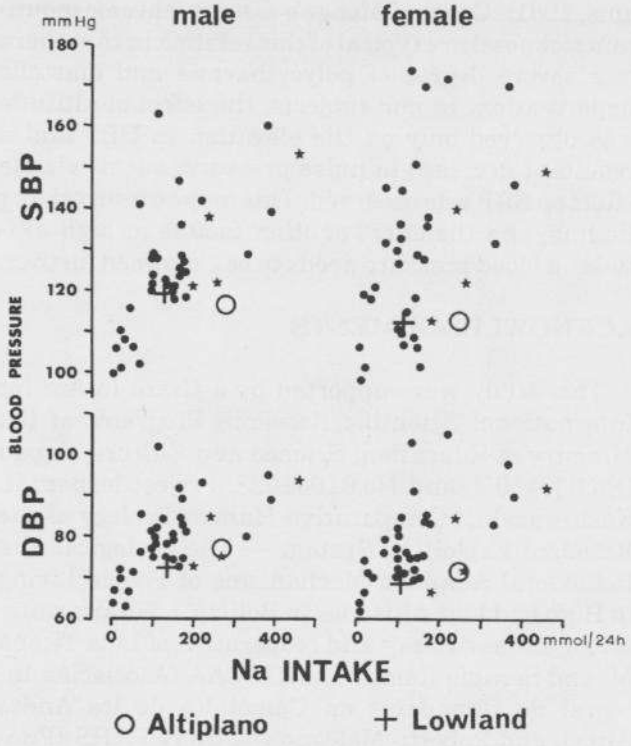


Fig. 2. Cross-cultural comparison of blood pressure and salt intake. Sources: Gleibermann (1973); Oliver et al. (1975); Young et al. (1987); Simmons et al. (1986); Hashimoto et al. (1989); Mancilha-Carvalho et al. (1989); Elliot (1990). Data from the present study are indicated by hollow circles for high-altitude subjects and by crosses for low-altitude subjects.

consumption survey (about 80 mmol of Na/1000 kcal of energy intake; Kashiwazaki et al., unpublished).

In the middle range of Na intake (90–200 mmol), intra-population studies have usually failed to show a strong relationship between individual blood pressure and urinary sodium excretion (Tobian, 1979; Schlierf et al., 1980; Staessen et al., 1981; Watt and Foy, 1982; Bulpitt et al., 1986; Moore, 1989). However, some recent INTERSALT studies indicated that sodium excretion is significantly related to BP in individuals and to a rise in BP with age (Rose and Stamler, 1989). The intra-individual variability of sodium intake, compared to much smaller inter-individual differences, may have obscured potential biological correlations between BP and urinary sodium excretion (Liu et al., 1979).

In contrast to intra-population studies, a positive relation between salt intake and blood pressure is usually found in inter-population studies (Dahl, 1972; Gleibermann, 1973). Figure 2 summarizes the inter-population relation between salt intake and blood pressure from available literature values, with additional plots of data from the present study. Plots of the present low-altitude subjects for both males and females are within the range of literature values, but the plots for the high-altitude subjects appear to be in the outlying position, suggesting that both SBP and DBP are lower than would be expected for their estimated Na intake.

Although virtually no comparable data exist on salt or Na intake for high-altitude populations in relation to blood pressure, a study in Tibet (altitude ranging from 2500 to 5000 m above sea level) showed an interesting finding on prevalence of hypertension with indirect evidence of habitual high salt intake (Sun, 1986). The prevalence of hypertension among Tibetans in Lhasa (3658 m) was significantly high and was more than twice that in the Hans who had migrated from lower altitudes 10–20 years before (19.1 vs. 8.73%). The higher prevalence of hypertension among the Tibetans has been explained by their dietary characteristics. They consume a large amount of salt — as much as 1 kg a month (i.e., more than 30 g per day), mainly in the form of salt-flavored tea. A low potassium intake may also play a role in the high prevalence of hypertension in Tibetans.

The prevalence of hypertension in subjects at high altitudes in the present study (20 years of age and over) was 1.3% (2/152), which is comparable with other high altitude native populations: 1.7% (3/181) in the Aymara of western Bolivia (Murillo et al., 1980), 1–2.9% in the Quechua of high-altitude Peruvian communities (Ruiz and Peñaloza, 1977), or in a Himalayan high-altitude community (Dasgupta et al., 1982). Thus, our subjects at high altitudes showed a low prevalence of hypertension; however, the study of Tibetans and Hans (Sun, 1986) suggests that we should be careful not to generalize the prevalence of hypertension to be always a rare occurrence at high altitudes, as was previously suggested.

A possible explanation of this low blood pressure with a relatively high Na intake in high-altitude subjects is that a high K intake may have played a role in preventing an elevation of BP. The populations with low sodium intake generally have a high potassium intake. Evidence from some epidemiological studies plus animal studies suggests that a major contributing cause of essential hypertension is a low potassium intake (Langford, 1983) and potassium intake is correlated inversely with blood pressure (Staessen et al., 1981; Bulpitt et al., 1986; Rose and Stamler, 1989). In studies of a single population with high salt intake, a weak but significant inverse correlation of BP with urinary potassium excretion has also been observed within the population (Khaw and Rose, 1982; Kihara et al., 1984; Hashimoto et al., 1989), with some negative data (Tuomilehto et al., 1980).

As is shown in Table 3, the urinary excretion of potassium in high-altitude subjects is about twice as high as that in low-altitude subjects, equalizing the ratio of Na/K in high-altitude subjects with that of low-altitude subjects. The estimated mean potassium intake in high-altitude subjects for both sexes (male: 130 mmol/24 h, female: 118 mmol/24 h) was similar to or higher than that of traditional 'no-salt' societies such as the unacculturated Yanomamo Indians on the border of Venezuela and Brazil (150 mmol/24 h; Oliver et al., 1975), the Yanomamo in the Brazilian Amazon (60–70 mmol; Mancilha-Carvalho et al., 1989), and the Gidra of the lowland Papua (72 mmol/24 h in males, 67 mmol/24 h in females; Inaoka et al., 1987). In populations with high sodium intake, urinary potassium excretion generally falls between 50 and 70 mmol/24 h. In view of these literature values for urinary potassium excretion, our high-altitude subjects exhibited exceptionally high excretion. More than half of daily potassium intake is derived from potatoes and chuño (Kashiwazaki et al., unpublished). The high potassium intake may partially negate the blood-pressure-raising effects of sodium in the native high-altitude Aymara.

### Altitude

The subjects in the present study did not show an inverse association between altitude and blood pressure such as has been observed in the Peruvian Quechua (Buck et al., 1968; Ruiz and Peñaloza, 1977). However, the results of multiple regression analysis indicate that altitude was the significant independent variable in increasing DBP and decreasing pulse pressure. Thus, it may be premature to reject the effect of a hypoxic environment on blood pressure. This finding coincides partly with the observations on Peruvian high- and low-altitude communities (Ruiz and Peñaloza, 1977); in that high-altitude communities have been reported to have a lower prevalence of hypertension and diastolic hypertension is more common than systolic hypertension, whereas in low-altitude communities, systolic hypertension is more common than diastolic hypertension. Chronic hypoxia is known to have a relaxing effect on smooth muscle, and the eventual effect on the arterial muscle is to produce vasodilation, probably oriented to improve blood oxygen supply to the tissues. Vasodilation, by diminishing peripheral resistance to flow, leads to a lowering of systemic blood pressure, particularly in SBP. This mechanism may counteract its effect on some increase in DBP by inducing polycythaemia, which raises blood viscosity and peripheral vascular resistance (Ruiz and Peñaloza, 1977; Heath and Williams, 1981). Cases of Monge's disease (chronic mountain sickness) are typical of this relation in that there is a severe degree of polycythaemia and diastolic hypertension. In our subjects, the effect of altitude was observed only on the elevation in DBP and a resultant decrease in pulse pressure, but no visible effect on SBP was observed. This may be a surprising finding, and the effect of other factors in high altitude on blood pressure needs to be examined further.

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