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ORIGINAL ARTICLE

Self-monitoring of home blood pressure with estimation of daily salt intake using a new electrical device

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We investigated a simple device to monitor daily salt intake at home and examined the relationship between salt excretion and morning blood pressure in order to enable patients to better manage daily salt intake and hypertension. The correlation between 24-h urinary salt excretion and measured value with salt monitor from overnight urine was significant ($n=224$, $r=0.72$, $P<0.001$). A total of 46 volunteers participated for more than 3 weeks by measuring daily salt intake and morning blood pressure. The relationship between predicted daily salt excretion and blood pressure was examined with use of 3-day moving average. Mean salt excretion and systolic blood pressure (SBP) significantly decreased by the end of the trial (i.e., salt excretion decreased from 158±31 to 149±30 mmol/day and SBP from 137±17 to 133±16 mm Hg). Of 46 participants, 18 (39%) had a significant correlation between predicted daily salt excretion and blood pressure ($r>0.4$, $P<0.05$, $n>21$), indicating sodium sensitivity. An additional 17% had a positive correlation that did not reach statistical significance ($0.2<r\leqslant0.4$), and the remaining 44% had no correlation ($r\leqslant0.2$). Mean decrease in blood pressure per decrease in salt (g) (17 mmol) intake in the 18 participants with a significant correlation was 3.3 mm Hg (SBP) and 1.5 mm Hg (diastolic blood pressure), which was higher than that reported for other studies. Hypertensive patients not using medication showed the largest decrease. We conclude that daily monitoring of salt intake and morning blood pressure will be useful for management of hypertension.

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Introduction

High-salt (NaCl) intake is a well-known risk factor for hypertension, cardiovascular disease[1–8] and stomach cancer.[9,10] The Japanese Ministry of Health and Welfare recommends a salt intake of less than 10 g/day, whereas the World Health Organization's recommendations restrict salt intake to 5 g/day or less and US,[11] UK and Japanese Society of Hypertension recommendations are 6 g (100 mmol)/day or less. Nevertheless, many people are still consuming more salt than recommended. Most people are not aware how much salt they consume.

Monitoring nutritional salt intake through sodium excretion has been popular, because the main route for sodium (Na) excretion is through the urine.[12–14] To collect a 24-h urine and measure the content is an accurate but difficult method for most patients, especially working people. In a previous study, creatinine and sodium content were measured in either a spot urine or overnight urine sample and 24-h sodium excretion (Na_{24}) was estimated from the ratio of 24-h predicted creatinine based on body weight, body height and age[15,16] or on lean body mass.[17] However, measuring creatinine content at home has a high cost. A 24-h sodium excretion (Na_{24}) value can also be estimated from overnight urinary sodium excretion (UNa_n).[18–20] We consider it ideal to measure salt intake at home in order to control average daily salt intake. Salt titrator sticks[18] and tapes[21] that detect chlorine ion are easy to use, but they are not accurate depending on the amount of urine applied to the tape and error in visual perception of colour change. To calculate overnight urinary sodium excretion, it is necessary to check urine volume and integrate it into sodium concentration.

Numerous studies have shown that some people are not sensitive to salt. Sensitivity and resistance to the effects of salt have been evaluated by the degree of blood pressure change between high-salt intake and low-salt diet.[22–24]

Recent reports suggest that morning surge is closely related to incidence of cardiovascular and

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cerebrovascular diseases.[25,26] Blood pressure and salt intake differ in individuals and on different days. Thus, it would be useful to measure morning blood pressure and salt intake with the new salt monitor and to examine the relationship between blood pressure and salt intake for a relatively long period. The aim of this study was to make participants accustomed to measuring morning blood pressure and salt intake to control hypertension in a way that is suitable for each individual.

Materials and methods

Study subjects

Two hundred and fifty healthy adults (53.9±16 years; male 62, female 188) participated to measure 24 h urinary salt excretion and overnight urinary salt excretion using ion electrode method.

Two hundred and twenty-four healthy adults (52.7±15.9 years; male 70, female 154) participated to measure 24-h urinary salt excretion by ion electrode method and overnight urine by new salt monitor.

A total of 46 adults (60.1±11.5 years; male 33) including 17 people who were taking antihypertensive medication participated to measure daily salt intake by new salt monitor using overnight urine and measure daily blood pressure. The main subgroup of people with systolic blood pressure (SBP) not less than 130 mm Hg, were recruited. The study protocol was approved by the ethics committee of Yokohama City University School of Medicine and all subjects gave informed consent to participate before enrolment.

Estimation of salt intake with the new salt monitoring system

The salt monitor we developed consists of a 1 l urine cup (10-cm diameter; 15-cm height) and an electrical device with volume and conductivity sensors (Figure 1). The volume sensor, which consists of 50 small resistant chips, measures overnight urine volume in the cup. The conductivity sensor consists of two gold-plated nickel metal plates. A temperature compensating circuit is used because conductivity changes with temperature. The NaCl concentration was adjusted by a correlation formula to be between the value obtained with the ion electrode method and the value for the conductivity method because measurement of concentration by conductivity is affected by other electrolytes such as potassium. V_n (overnight urine volume) was measured by resistance sensor and $NaCl_n$ (overnight urinary sodium chloride concentration) was measured by conductivity sensor; then, values were integrated. Formula (1) was derived by the regression analysis between $NaCl_{24}$ (24-h salt excretion) and $NaCl_n \times V_n$ by the ion electrode. The value for $NaCl_{24}$ was estimated by Formula (1) using a computer calculator and displayed on the monitor panel:

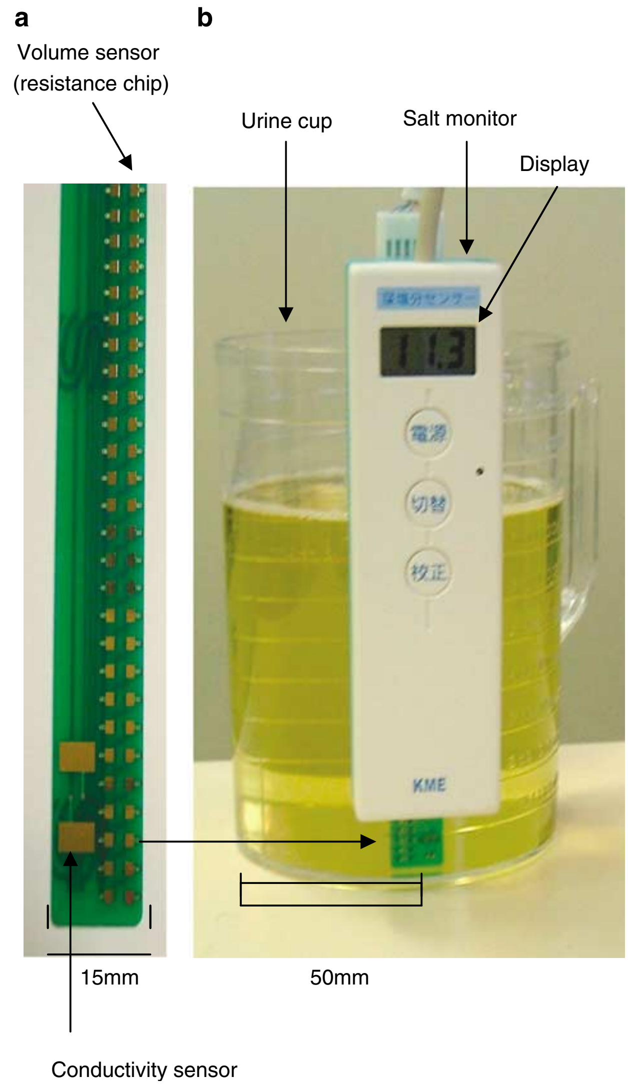

Figure 1 Salt monitor for estimation of daily salt intake. (**a**) Conductivity sensor and volume sensor. (**b**) Salt monitor and urine cup (1-l volume). Daily salt excretion (g/day) is shown on the display.

$$Y = 1.95X + 4.5\text{g/day}(Y: \text{NaCl}_{24}, X: \text{NaCl}_n \times \text{V}_n)$$
$$[1.95X + 77.6\text{mmol/day})] \quad (1)$$

Before going to bed, participants voided completely and discarded the urine. Overnight urine was collected in the 1-l urine cup. After awakening, participants voided and placed the urine in the urine cup, adding any urine they had voided overnight. Participants were asked to collect the urine for approximately 8 h. Then they set the salt monitor and recorded the display value. The relationship between $NaCl_{24}$ from 24-h urine determined by ion electrode method and $NaCl_{24}$ estimated from overnight urine by the new salt monitor and ion electrode method was examined in 224 subjects.

Daily monitoring of salt intake and morning blood pressure
Forty-six participants measured daily salt intake by the new salt monitor using overnight urine, and measured blood pressure before breakfast and taking morning medicine using an arm cuff equipped for automatic inflation, after they had been sitting for 1–2 min. Participants were asked to monitor salt intake and blood pressure more than 3 weeks. During the first 2 weeks, they ate as usual. Subjects who could not decrease salt excretion to less than 137 mmol (8 g)/day were asked to reduce salt intake from the beginning of the third week. The relationship between blood pressure and salt excretion was examined using the 3-day moving average, which smoothes a time series by averaging each successive group of data points from the beginning to the end of the study.

Hypertension was defined as an average SBP in the first 3 days of 140 mm Hg or greater, diastolic blood pressure (DBP) 90 mm Hg or greater or use of antihypertensive medication. Participants who showed a significant correlation in either measurement without modification or 3-day moving average were identified as salt sensitive (group A), and subjects without a significant correlation but $r > 0.2$ were placed into group B. Other subjects were assumed to be salt resistant.

Statistical analysis
Values are expressed as mean ± s.d. or mean ± s.e.m. Statistical comparisons between mean values at the first 7 days of the study and values for the last 7 days were performed with paired *t*-test. Simple linear regression analysis was used to estimate the relationship between blood pressure and salt excretion for each participant. Analyses were performed using Microsoft Excel Statistics 2004 for Windows (SSRI Co. Ltd, Japan, Tokyo) and SPSS version 11 (SPSS Inc., Chicago, IL, USA). A *P*-value less than 0.05 was considered statistically significant.

Results

The correlation between 24-h urinary salt excretion with ion electrode method and measured value with new salt monitor using overnight urine was significant ($r = 072$, $P < 0.001$) (Figure 2). The duration of participation of 46 participants varied from 21 to 66 days (mean, 28 days). Mean salt excretion and SBP for all participants decreased significantly from 158 ± 31 mmol (average for first 7 days) to 149 ± 30 mmol (average for last 7 days) and from 137 ± 17 to 133 ± 16 mm Hg, respectively. Study participants (31/46, 67%) significantly decreased salt excretion.

A significant correlation was found for 18 of the 46 subjects over the duration of the study; an example is shown in Figure 3. Unmodified data

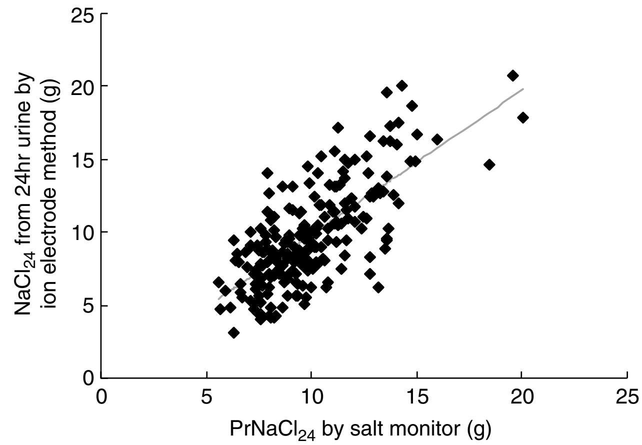

Figure 2 Relationship between values of 24-h urinary sodium chloride excretion ($PrNaCl_{24}$) predicted from overnight urine by new salt monitor and 24-h urinary sodium chloride excretion ($NaCl_{24}$) by ion electrode method ($n = 224$, $r = 0.72$, $P < 0.001$).

(left) and 3-day moving averages (right) showed a significant correlation, especially the 3-day moving average. Participants were placed into group A, B or C based on correlation level (*r*, correlation coefficient between morning blood pressure and estimated 24-h salt excretion):

A: $r > 0.4$ ($P < 0.05$); B: $0.2 < r \leqq 0.4$, $0.05 \leqq P < 0.3$; C: $r \leqq 0.2$ ($P \geqq 0.3$):

As shown in Table 1, 39% of subjects belonged to group A, with 17% in group B and 44% in group C. People who were hypertensive without medication were largely in group A. In group A, seven of 18 subjects showed significant correlation only with 3-day moving averages. The regression coefficients and the slope (mm Hg/salt (g, 17 mmol)) of regression line for group A are shown in Table 2. For these subjects, mean decrease in blood pressure was 3.3 mm Hg SBP and 1.5 mm Hg DBP. For hypertensive subjects without medication, mean decrease in blood pressure was 4.3 mm Hg SBP and 2.5 mm Hg DBP. Among subjects who were taking antihypertensive medication, before and during the study, mean decrease in blood pressure was 3.1 mm Hg SBP and 1.3 mm Hg DBP. In normotensive individuals, mean decrease was 2.2 mm Hg SBP and 0.4 mm Hg DBP.

Discussion

This study evaluated a simple method for estimation of 24-h urinary salt excretion to monitor daily salt intake at home; additionally, we examined the relationship between salt excretion and morning blood pressure in each individual more than 3 weeks. Based on our formula (1) to estimate daily salt intake from overnight urine (see Materials and methods), minimum salt excretion was 4.5 g (77.6 mmol)/day. Some people are known to excrete

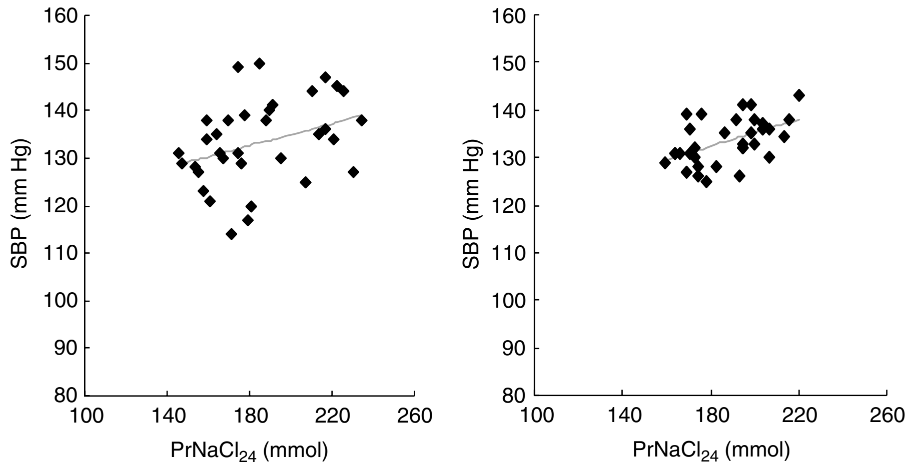

Figure 3 Example of relationship between SBP and 24-h urinary salt excretion ($PrNaCl_{24}$) predicted by salt monitor (64-year-old man; 34 days of data). $r=0.42$ ($P<0.05$) (left panel) and $r=0.5$ ($P<0.001$) for 3-day moving average (right panel).

Table 1 Three correlation levels between salt excretion ($PrNaCl_{24}$) and morning blood pressure

Group	*A*	*B*	*C*
Hypertensive subjects	13	4	15
No medication (untreated)	7	2	6
On antihypertensive medication	6	2	9
Normotensive subjects	5	4	5
All subjects	18	8	20
Ratio (%)	39	17	44

A: $r>0.4$ ($P<0.05$); B: $0.4\geqslant r>0.2$ ($0.05\leqslant P<0.3$); C: $r\leqslant 0.2$ ($P\geqslant 0.3$). *r*, regression coefficients of the correlation between salt excretion and morning blood pressure; $PrNaCl_{24}$, 24-h urinary salt excretion predicted by salt monitor.

below 3 g (50 mmol)/day and one report suggests that salt intake should be reduced to 3 g (50 mmol)/day.[27] In our study design phase, we studied power function (2) instead of linear function (1).

$$Y = 5.76(X)^{0.53}(\text{g/day}),$$
$$Y = 21.92(X)^{0.53}(\text{mmol/day}) \quad (2)$$

However, there was no difference in mean square error of the estimate between formulas. In people with lower salt excretion, formula (2) resulted in values nearer 24-h excretion, but in people with higher salt excretion, formula (1) came nearer to the 24-h value. Because few of our subjects had a baseline salt intake less than 85 mmol (5 g), we adopted formula (1) at the first stage to attain an intake less than 100 mmol (6 g). The correlation between 24-h urinary salt excretion and measured value with our salt monitor was significant, but not sufficient. The difference between our new salt monitor and ion electrode method was small and regression coefficients were 0.72 and 0.75, respectively. This was largely owing to a difference in the proportion of overnight urine and 24-h urine volumes among individuals, a difference that is due to individual circadian rhythms. Additional contributors would be inter-individual differences in renal function, interval between dinnertime and bedtime, antidiurenic hormone (ADH) function and in sweating. Some studies have demonstrated good correlations between overnight urinary salt and 24-h urinary salt,[18–20] whereas others found an absence of correlation[28,29] and some suggest seven or 14 measurements are needed to replace 24-h urine collection.[19,30] Urinary salt excretion is affected not only by the previous day's salt intake, but also by the salt intake of the previous 3 or 4 days.[14] We examined the relation of 24-h urinary salt excretion and overnight urinary salt excretion for eight subjects over 14 days. The correlation coefficient of the 3-day moving average was high (mean 0.85 ± 0.08; range, 0.76–0.98). Thus, we expected to be able to manage daily relative salt intake, although there was a possibility that the predicted salt value would differ from the real value, if a relatively long period was required for representative results and we used the moving 3-day moving average.

Daily blood pressure changes not only because of salt intake but also because of temperature change,[31] day of the week[32] and change of sympathetic nervous system activity. As morning blood pressure in particular fluctuates, it takes a long interval to examine accurately the relationship between salt excretion and morning blood pressure. We decided on 3 weeks as the minimum duration of participation in the trial. As a result, the relationship between salt intake and blood pressure seemed to be clear for each individual. The target for salt excretion differed for each individual based on correlations between salt excretion on the panel and morning blood pressure. One advantage of the current study was that it allowed salt-sensitive individuals to see their own salt–blood pressure pattern, as well as to see the gains made in blood pressure with reduction in salt intake. Self-monitoring of morning blood pressure and

Table 2 The regression coefficients and the slope of regression line between morning blood pressure and daily salt excretion in group A

	SBP		*DBP*	
	r	a *(mm Hg/g)*	r	a *(mm Hg/g)*
Hypertensive subjects	0.55±0.04	3.7±0.7	0.52±0.05	2.0±0.6
No medication (untreated)	0.6±0.04	4.3±1.1	0.59±0.08	2.5±1.0
Antihypertensive medication	0.4±0.03	3.1±0.8	0.45±0.04	1.3±0.3
Normotensive subjects	0.59±0.08	2.2±0.8	0.44±0.13	0.4±0.2
All subjects	0.56±0.04	3.3±0.5	0.54±0.04	1.5±0.4

Values are mean±s.e.m. *r*, regression coefficients; *a*, slope of regression line (mm Hg/salt excretion (g, 17 mmol)).
Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure.

daily salt intake for more than 3 weeks, as was performed in the current study, will be useful for the physicians and patients to identify who is salt sensitive and who is salt resistant and to decide on target goals, including goals for patients who already take antihypertensive medication. The mean decrease in SBP with reduction of salt excretion in our group A was higher than that reported for other studies.[23,27,33] It is thought that some of these studies included both salt-sensitive and salt-resistant subjects and our data included the 3-day moving average, and the blood pressure data were morning blood pressure, which would explain in part why the mean decrease in blood pressure of our data in group A was higher than that of the other data. In our study, about 44% of the subjects seemed to be salt resistant. Epidemiological studies have suggested that salt intake is related to risk for gastric cancer,[9,10] an important malignancy in Japan. Therefore, regardless of salt sensitivity in terms of blood pressure, it is important to reduce salt intake. The new salt monitor will be useful for all patients who need to regulate salt intake.

In this study, mean salt excretion decreased significantly and 67% of subjects reduced salt intake, but the reduction level was not sufficient. We relied on each individual to change dietary and other life-style factors.

We are now mounting a communication module in the salt monitor. Patients will be able to send data on daily salt intake, as well as other data such as blood pressure, electrocardiography tracings and weight to the medical centre. By using this method and providing more guidance to patients, greater salt reduction is expected, along with possible gains in other dietary factors such as daily calories and calories from fats.

In conclusion, the new salt monitor using overnight urine is a simple device for effectively monitoring salt intake over long periods of time. Self-monitoring of home blood pressure and daily salt intake for more than 3 weeks could help physicians and patients manage risk factors for hypertension in a way that is suitable for each individual.

What is known on this topic

- A 24-h sodium excretion value can be estimated from overnight urinary sodium excretion.[18–20]
- Salt titrator sticks and tapes are known as simple method to detect the concentration of salt in overnight urine.[18,21]
- Sensitivity and resistance to the effects of sodium were evaluated by the degree of BP change between high-salt diet and low-salt diet.[22–24]

What this study adds

- A new simple method to monitor daily salt intake was developed.
- Self-monitoring of morning blood pressure and daily salt intake by this device for more than 3 weeks and examining the relationship with use of 3-day moving average will be useful to identify who is salt sensitive.
- Measuring daily morning blood pressure and overnight urine by this device at home will be useful for the management of hypertension suitable for each individual.

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