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ORIGINAL ARTICLE

Within-country variation of salt intake assessed via urinary excretion in Japan: a multilevel analysis in all 47 prefectures

Ken Uechi[1], Keiko Asakura[2,3], Shizuko Masayasu[4] and Satoshi Sasaki[2]

Salt intake in Japan remains high; therefore, exploring within-country variation in salt intake and its cause is an important step in the establishment of salt reduction strategies. However, no nationwide evaluation of this variation has been conducted by urinalysis. We aimed to clarify whether within-country variation in salt intake exists in Japan after adjusting for individual characteristics. Healthy men ($n = 1027$) and women ($n = 1046$) aged 20–69 years were recruited from all 47 prefectures of Japan. Twenty-four-hour sodium excretion was estimated using three spot urine samples collected on three nonconsecutive days. The study area was categorized into 12 regions defined by the National Health and Nutrition Survey Japan. Within-country variation in sodium excretion was estimated as a population (region)-level variance using a multilevel model with random intercepts, with adjustment for individual biological, socioeconomic and dietary characteristics. Estimated 24 h sodium excretion was 204.8 mmol per day in men and 155.7 mmol per day in women. Sodium excretion was high in the Northeastern region. However, population-level variance was extremely small after adjusting for individual characteristics (0.8 and 2% of overall variance in men and women, respectively) compared with individual-level variance (99.2 and 98% of overall variance in men and women, respectively). Among individual characteristics, greater body mass index, living with a spouse and high miso-soup intake were associated with high sodium excretion in both sexes. Within-country variation in salt intake in Japan was extremely small compared with individual-level variation. Salt reduction strategies for Japan should be comprehensive and should not address the small within-country differences in intake.
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INTRODUCTION

Salt reduction is a cost-effective dietary strategy for preventing hypertension, cardiovascular disease and other noncommunicable diseases.[1,2] Although the World Health Organization (WHO) recommends a daily adult salt intake of <5 g per day to prevent these noncommunicable diseases,[3] intake in most countries exceeds this amount.[4] To achieve this level of reduction, the WHO also recommends that the food industry make efforts to reduce salt content in processed food.[3] A strategic reduction in salt content in processed foods in the United Kingdom did in fact reduce salt intake at the population level.[5] A similar salt reduction might not be expected in Japan; a 24 h urine collection study by Asakura *et al.*[6] in 2013 estimated population-level sodium excretion at 206.0 mmol per day (12 g of salt per day) in men and 173.9 mmol per day (10 g of salt per day) in women in Japan. In Japan, the major dietary source of salt is when it is added to meals prepared at home,[7,8] which is in contrast to the United Kingdom, where the major source of salt is that added to processed foods.[8] In addition, several intervention programs established for individuals in Japan, such as the monitoring of salt concentrations in meals by electronic devices, education (including cooking classes), and counseling by a dietitian, have been effective at raising awareness about salt reduction and reducing actual salt intake; however, the reproducibility and feasibility of these intensive programs in whole populations remain unclear.[9–11] Even now, the Japanese government has not established solutions to overcome excess salt intake in the Japanese population.[12]

Against this background, the evaluation of within-country variation in salt intake may be an important step in clarifying dietary problems related to salt and advancing salt reduction. In the United Kingdom, population sodium excretion was higher in Scotland than in England and Wales,[13] and within-Scotland variation of dietary intake was explained by differences in socioeconomic status.[14] In Japan,

[1]Department of Social and Preventive Epidemiology, Division of Health Sciences and Nursing, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan; [2]Department of Social and Preventive Epidemiology, School of Public Health, The University of Tokyo, Tokyo, Japan; [3]Interfaculty Initiative in Information Studies, The University of Tokyo, Tokyo, Japan and [4]Ikurien-naka, Ibaraki, Japan
Correspondence: Professor S Sasaki, Department of Social and Preventive Epidemiology, School of Public Health, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
E-mail: stssasak@m.u-tokyo.ac.jp
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population salt intake has been higher in the Northeast region than in other regions since the 1950s.[15] To date, however, no nationwide estimations of within-country variation in salt intake have been conducted by urinalysis among all 47 prefectures in Japan. If the within-country variation in salt intake was large, exploring the cause of that variation would contribute to the establishment of effective salt reduction strategies.

Here, we conducted a multilevel cross-sectional study to evaluate individual- and population-level daily sodium excretion estimated by the 'spot urine' method[16] from Japanese men and women aged 20–69 years in all 47 prefectures of Japan. We then aimed to use multilevel analysis to evaluate whether the within-country variation in salt intake assessed by sodium excretion remained after adjusting for individual biological, socioeconomic and dietary characteristics.

METHODS

Study subjects

We recruited 2350 apparently healthy men and women aged 20–69 years living in all 47 prefectures of Japan. In each prefecture, we first recruited five dietitians working in five different welfare facilities as research dietitians. These research dietitians were then instructed to invite their coworkers at the welfare facility to participate in the study as participants. Each prefecture included 50 participants stratified by sex (men and women) and five 10-year age groups (20–60s). Research dietitians were requested to ensure that each sex and age group included five participants for each prefecture. The study recruitment and procedure have been described in detail elsewhere.[16] This study was conducted according to the guidelines of the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the Ethics Committee of the University of Tokyo, Faculty of Medicine (approval no. 10299, approval date 1 November 2013). All participants were informed of the aims and procedure of the study by the study dietitians and then gave written consent to participate. The study was conducted in January and February of 2014.

Definition of study region

To determine study regions, we adopted the region categories defined by the National Health and Nutrition Survey 2013 (NHNS-2013), which was conducted in a nationally representative population of Japan.[17] The NHNS-2013 categorized study regions into 12 regions based on the 47 prefectures of Japan as follows (in order from North to South): Hokkaido, Tohoku (6 prefectures), Kanto-1 (4 prefectures), Kanto-2 (5 prefectures), Hokuriku (4 prefectures), Tokai (4 prefectures), Kinki-1 (3 prefectures), Kinki-2 (3 prefectures), Chugoku (5 prefectures), Shikoku (4 prefectures), Kyushu-1 (4 prefectures) and Kyushu-2 (4 prefectures). We adopted these region categories instead of the 47 individual prefectures because population-level average food intakes were only available for these 12 regions in NHNS. The population-level average food intake levels were used as markers of regional characteristics for further examination of those effects on individual salt intake.

Daily urinary sodium excretion

We estimated daily sodium excretion by individuals as a marker of daily salt intake using the 'spot urine' method developed for our previous study.[16] Participants were asked to provide three spot urine samples in the afternoon on three nonconsecutive days. Daily sodium excretion was estimated from these three spot urine samples as follows: daily sodium excretion (mmol per day) = average of three spot urinary sodium concentrations (mmol l^{-1})/average of three spot urinary creatinine concentrations (mmol l^{-1}) × estimated daily creatinine excretion (mmol per day), where the estimated daily creatinine excretion (mmol per day) = 2.84 × sex (men = 1, women = 0)+0.05 × age (year) − 0.001 × square of age (year × year) +0.144 × weight (kg)+0.01 × height (cm) − 1.14. This estimation method was validated using two 24 h urinary sodium and creatinine excretions as references and is therefore suitable for estimating habitual sodium excretion in individuals.[16]

Individual biological, socioeconomic and dietary characteristics

Individual variables were obtained by measurements and a questionnaire, and were then included in the model. Age (year), sex (male or female), body mass index (BMI) (kg m^{-2}, measured as weight (kg) divided by the square of measured height (m)) and physical activity level (metabolic equivalents × h)[18] were identified in a previous study as potentially affecting sodium excretion.[6] The presence of hypertension (yes or no), hyperlipidemia (yes or no) and diabetes (yes or no) was also included in the model when they could not be sufficiently excluded at the recruitment stage. Smoking (no, former or current), education (university or equivalent, junior college or equivalent, high school, junior high school and others), living alone (yes or no) and living with a spouse (yes or no) were also included as variables reflecting socioeconomic status. To investigate the dietary intake of individuals, the brief-type self-administered diet history questionnaire (BDHQ) was used, which has been validated against a 16-day semi-weighed dietary record.[19,20] In the present study, bread, noodles, miso soup, pickled vegetables, fish intake and dairy products (g per 1000 kcal) were included as markers of individual dietary characteristics based on the major dietary sources of sodium in the Japanese population.[7] Although seasonings (for example, soy sauce) are the main source of salt intake in the Japanese diet,[7] we could not include soy sauce intake in the model because intake levels of each seasoning are only summarized as 'salt intake from seasonings' in the BDHQ. In addition, a validation study for the BDHQ suggested that the estimation accuracy of 'salt intake' (including 'from seasoning') was not very high.[19] Hence, the model did not include soy sauce intake or 'salt intake from seasonings'.

Statistical analysis

Before the analysis, we excluded participants who could not complete all study procedures ($n = 5$), those who missed the collection of three spot urine samples ($n = 6$), those who used diuretics ($n = 16$), those with estimated energy intake by the BDHQ of <600 kcal ($n = 7$) and >4000 kcal ($n = 12$), and those whose estimated sodium excretion was less than the fifth percentile value or >95th percentile value in the distribution stratified by sex ($n = 231$). Finally, the data obtained from the remaining 2073 participants (1027 men and 1046 women) were analyzed in this study.

To grasp within-country variation in sodium excretion, we estimated variation as a population-level variance estimated by multilevel regression analysis with random intercepts.[21,22] In the present analysis, the model included individual sodium excretion as a dependent variable and individual-level characteristics (biological characteristics, social status and dietary intake) as independent variables. In addition, the study region was included in the model as a random effect; that is, we allowed the intercept of each study region to vary randomly across regions. Therefore, variation in regional-level sodium excretion could be estimated as a random component; that is, overall variance was divided into individual-level variance (that is, between-individual differences) and population-level variance (between-region differences).

On the basis of these characteristics of multilevel analysis, we first estimated the mean value of daily sodium excretion of all participants and by the 47 prefectures, and 12 NHNS-2013-based regions. Given the large difference in salt intake between men and women in the Japanese population,[6,16] we first stratified participants by sex and then conducted the subsequent analyses.

In the next step, we estimated population-level variance among 12 regions defined by NHNS-2013 as random intercepts of the regression model, and then examined the relationship between individual sodium excretion and individual-level variables to clarify whether the population-level variance was still observed after all individual-level variables were adjusted. When population-level variance was observed, the proportion of population-level variance in the overall variance was calculated as the intra-class correlation coefficient (ICC). A large ICC indicates that large within-country variation in sodium excretion exists and that individual sodium excretion is strongly influenced by resident region. In the case of a large ICC, we planned additional analyses to clarify the cause of within-country variation in sodium excretion by examining population-level dietary characteristics in the regression model. We conducted all statistical analyses using Proc Mixed procedure in SAS (version 9.4, SAS Institute, Cary, NC, USA) and set significance at $P<0.05$.

Table 1 Basic characteristics of study participants

	Men		*Women*		*All*	
	n = *1027*		n = *1046*		n = *2073*	
	Mean and s.d. or *n* (%)					
Age, years	44.3	13.6	44.4	13.6	44.3	13.6
Age distribution, n *(%)*						
20–29	202	(19.8)	207	(19.8)	409	(19.7)
30–39	209	(20.4)	214	(20.5)	423	(20.4)
40–49	212	(20.6)	211	(20.2)	423	(20.4)
50–59	208	(20.3)	211	(20.2)	419	(20.2)
60–69	196	(19.1)	203	(19.4)	399	(19.3)
Height, cm	169.9	6.0	156.7	5.7	163.2	8.8
Weight, kg	68.3	10.2	54.6	8.4	61.4	11.6
Body mass index, kg m^{-2}	23.6	3.2	22.3	3.4	23.0	3.4
Physical activity level, MET × h	38.2	6.3	38.6	5.8	38.4	6.0
Spot urine collection[a]						
Na concentration, mmol l^{-1}	151.4	46.6	138.9	48.3	145.1	47.8
K concentration, mmol l^{-1}	49.0	19.5	49. 5	21.6	49.3	20.5
Creatinine concentration, mg dl^{-1}	119.2	47.7	91.4	40.4	105.2	46.3
Blood pressure, mm Hg						
Systolic	128.5	14.8	119.7	15.5	124.1	15.8
Diastolic	81.0	11.0	75.2	10.9	78.0	11.3
Past or current treatment, n *(%)*						
Hypertension	147	(14.3)	88	(8.4)	235	(11.3)
Hyperlipidemia	113	(10.9)	84	(8.0)	196	(9.5)
Diabetes mellitus	27	(2.6)	10	(1.0)	37	(1.8)
Smoking status, n *(%)*						
No	327	(31.8)	759	(72.8)	1086	(52.5)
Former	302	(29.4)	114	(10.9)	416	(20.1)
Current	398	(38.8)	170	(16.3)	568	(27.4)
Educational status, n *(%)*						
Junior high school and other	26	(2.5)	57	(5.5)	83	(4.0)
High school	233	(22.7)	376	(36.0)	609	(29.4)
Junior college or equivalent	300	(29.2)	450	(43.1)	750	(36.2)
University or equivalent	467	(45.5)	162	(15.5)	629	(30.4)
Living status, n *(%)*						
Living alone	86	(8.4)	129	(12.3)	215	(10.4)
Living with spouse	719	(70.0)	572	(54.7)	1291	(62.3)
Food intake, g per 1000 kcal (median (IQR))						
Bread	13.8	(21.9)	17.7	(24.9)	15.7	(23.5)
Noodle	35.0	(28.8)	27.3	(23.6)	30.7	(27.0)
Miso soup	73.6	(76.0)	75.3	(69.9)	74.9	(72.2)
Pickled vegetables	5.6	(8.2)	5.7	(9.1)	5.7	(8.8)
Fish	35.5	(28.1)	37.7	(28.9)	36.7	(28.5)

Abbreviations: IQR, interquartile range; MET, metabolic equivalent.
[a]Average of multiple measurements (three spot urine collections per participant).

RESULTS

Despite the exclusion of several study participants, age and sex distributions were well balanced. In addition, some participants reported having hypertension (11.3%), hyperlipidemia (9.5%) and diabetes (1.8%), but these accounted for only small percentages of the overall participants (Table 1). Most participants had lived in their prefecture for 20 or more years, suggesting that they were affected by the dietary habits related to salt intake in that region (Table 2). The

Table 2 Summary of estimated urine excretions for 12 regions defined by National Health Nutrition Survey Japan

	Numbers of participants (n, (men/women))	Percentage of long-term resident[b]	*Estimated daily creatinine excretion*[a] mg per day (mean	s.e.)	*Estimated daily sodium excretion* mmol per day[c] (mean	s.e.)	mmol per gCr[d] (mean	s.e.)
All	2073 (1027/1046)	89	1222.8	7.2	180.0	1.3	152.2	1.1
Men	1027	89	1505.0	5.8	204.8	1.9	137.5	1.3
Women	1046	89	945.7	4.7	155.7	1.6	166.6	1.7
Regions[e]								
Hokkaido	39 (19/20)	100	1204.5	53.6	186.5	9.1	165.8	11.0
Tohoku	259 (124/135)	88	1246.1	20.9	189.0	3.8	157.3	3.2
Kanto-1	175 (85/90)	79	1217.4	25.0	184.0	4.8	156.3	4.0
Kanto-2	225 (113/112)	90	1228.1	20.3	184.1	4.2	153.5	3.3
Hokuriku	178 (87/91)	93	1209.2	23.7	184.5	4.5	158.7	4.0
Tokai	179 (89/90)	87	1200.2	24.1	176.6	4.5	149.9	3.5
Kinki-1	132 (68/64)	89	1251.0	28.7	182.9	5.5	149.9	4.2
Kinki-2	133 (66/67)	85	1261.9	30.3	180.8	5.2	149.0	4.5
Chugoku	226 (115/111)	94	1201.2	21.6	180.6	4.2	157.3	4.0
Shikoku	175 (85/90)	93	1227.6	26.2	172.9	4.7	145.3	3.7
Kyushu (North)	179 (90/89)	89	1227.1	23.9	176.1	4.3	147.6	3.4
Kyushu (South)	173 (86/87)	90	1195.5	24.6	162.1	3.9	140.1	3.3

[a]Estimated daily creatinine excretion (mg per day) = estimated daily creatinine excretion (mmol per day) × 1000/8.84, where estimated daily creatinine excretion (mmol per day) = 2.84 × sex (men = 1, women = 0)+0.05 × age (year) − 0.001 × square of age (year × year)+0.144 × weight (kg)+0.01 × height (cm) − 1.14.[b]Percentage of participants who lived in the prefecture for 20 or more years.[c]Estimated daily sodium excretion (mmol per day) = mean of three spot Na concentrations (mmol l^{-1})/mean of three spot creatinine concentrations (mmol l^{-1}) × estimated daily creatinine excretion (mmol per day).
[d]Estimated daily sodium excretion (mmol per gCr) = estimated daily sodium excretion (mmol per day)/estimated daily creatinine excretion (mg per day) × 1000.
[e]Categorized by National Health and Nutrition Survey Japan. Regions are listed in order from North to South.

average estimated daily sodium excretion was 180.0 mmol per day (10.6 g of salt per day) in overall participants, 204.8 mmol per day (12.0 g of salt per day) in men and 155.7 mmol per day (9.1 g of salt per day) in women (Table 2). Sodium excretion was >150 mmol per day (8.8 g of salt per day) in all regions and prefectures, as shown in Table 2 and Supplementary Table 1. When these values were depicted on the map, population-level sodium excretion was high in the North and low in the South (Figure 1). This North–South gradation was observed even when the map was stratified by sex (Figure 2).

Although an apparent North–South gradation of sodium excretion was observed, the population-level variance in sodium excretion was extremely small (Table 3). Without adjusting for individual-level variables (Model 0), the ICC was 0.01 (1% of overall variance) and 0.02 (2% of overall variance) in men and women, respectively (Table 3). Even when significant individual-level variables were adjusted in Model 3, the population-level variance remained, albeit at the markedly low ICC of 0.008 (0.8% of overall variance) and 0.02 (2% of overall variance) in men and women, respectively (Table 3). The examination using the individual 47 prefecture categories showed larger within-country variation, but the ICC remained small (ICC was 0.0 for men and 0.03 for women in Model 3 when 47 prefectures were adopted).

In addition, some individual-level variables were significantly associated with sodium excretion when considered as population-level variance. High BMI ($\beta = 4.0$ in men and $\beta = 4.1$ in women) and living with a spouse ($\beta = 10.3$ in men and $\beta = 7.3$ in women) were associated with high sodium excretion. Low education status was associated with high sodium excretion in men ($\beta = 23.7$), but only marginally with low sodium excretion in women ($\beta = -14.9$, $P < 0.10$). Regarding dietary intakes, high miso-soup intake ($\beta = 0.09$ in men and $\beta = 0.06$ in women) and noodle intake ($\beta = 0.2$ in men) were significantly associated with high sodium excretion (Table 3).

DISCUSSION

In this multilevel cross-sectional study, we found that the average sodium excretion of Japanese adults was 180.0 mmol per day (10.6 g per day of salt). This result means that salt intake in the Japanese population was almost twofold the 5 g per day targeted by the WHO as an upper limit of daily salt intake. In fact, although population-level sodium excretion was high in the Northeastern region (Tohoku, two Kanto regions and Hokuriku), population-level variance in sodium excretion was extremely small compared with individual-level variance, suggesting that a comprehensive salt reduction strategy would be more suitable for Japanese populations than a strategy oriented toward the in-country variation of salt intake.

The existence of large within-country variation in sodium intake in Japan, namely high salt intake in the Northeastern region, is believed to be common knowledge in Japan. However, our present results suggest that this notion is no longer true. In accordance with earlier studies, the within-country variation in sodium intake has decreased with time. In the 1950s, Dahl[15] indicated a large difference in salt intake as estimated by 24 h urine of 26 g per day in Akita (Northern prefecture) and 14 g per day in Hiroshima (Southern prefecture). Our present results were lower and narrower than those values, at 191.4 mmol per day (11.3 g of salt per day) in Akita and 180.1 mmol per day (10.6 g of salt per day) in Hiroshima (Table 2). Dietary survey of Tsubono *et al.*[23] using a three-day weighed food record in the early 1990s showed that population-level variance accounted for 8–10% of overall variance in sodium intake *vs.* our present value of 0.8–2% (Table 3). One possible explanation for this decrease in within-country variation is the influence of social development (especially development of the food industry and distribution systems) and westernization of the Japanese diet. The apparent increase in the distribution and consumption of processed foods might have led to the small within-country variation of sodium intake. This notion is consistent with a report by Asakura *et al.*,[7] who found that the salt intake from

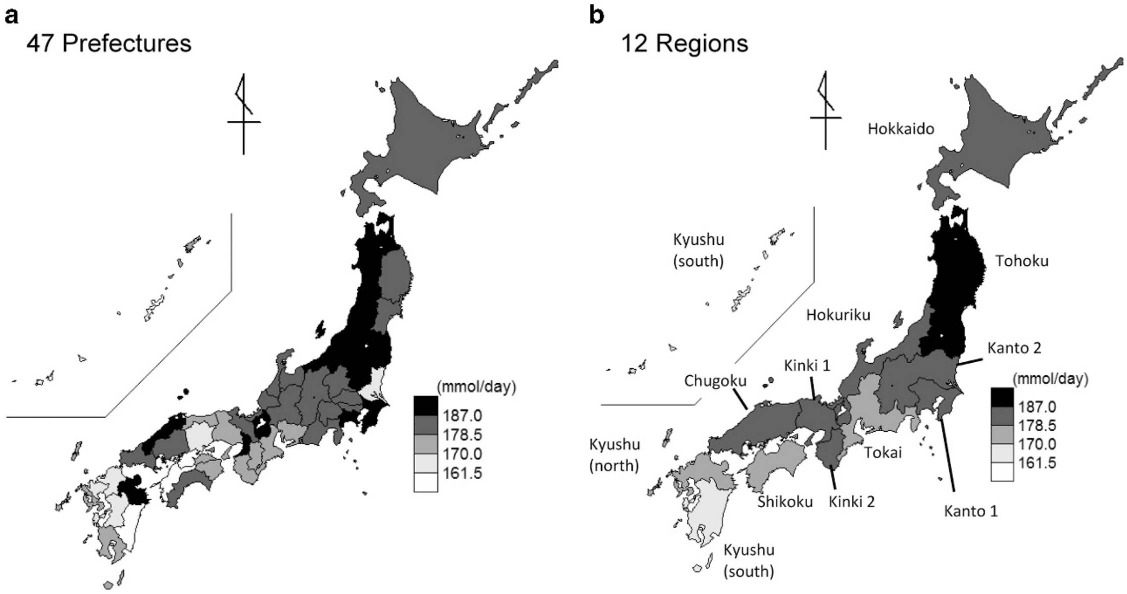

Figure 1 Map of population-level estimated daily sodium excretion. The map shows estimated sodium excretion by (**a**) 47 prefectures and (**b**) 12 regions defined by the National Health and Nutrition Survey Japan. Estimated daily sodium excretion (mmol per day) = mean of three spot Na concentrations (mmol l^{-1})/ mean of three spot creatinine concentrations (mmol l^{-1}) × estimated daily creatinine excretion (mmol per day), where estimated daily creatinine excretion (mmol per day) = 2.84 × sex (men = 1, women = 0)+0.05 × age (year) − 0.001 × square of age (year × year)+0.144 × weight (kg)+0.01 × height (cm) − 1.14.

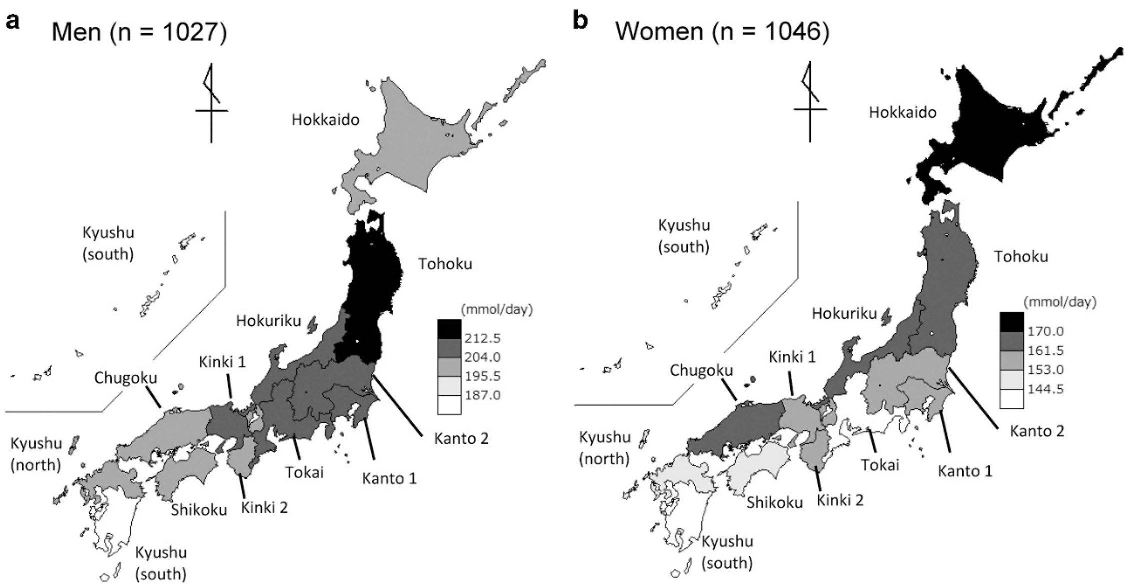

Figure 2 Sex-stratified map of population-level estimated daily sodium excretion for 12 regions. The map shows estimated sodium excretion by sex ((**a**) men and (**b**) women) in the 12 regions defined by the National Health and Nutrition Survey Japan. Estimated daily sodium excretion (mmol per day) = mean of three spot Na concentrations (mmol l^{-1})/mean of three spot creatinine concentrations (mmol l^{-1}) × estimated daily creatinine excretion (mmol per day), where estimated daily creatinine excretion (mmol per day) = 2.84 × sex (men = 1, women = 0)+0.05 × age (year) − 0.001 × square of age (year × year)+0.144 × weight (kg)+0.01 × height (cm) − 1.14.

home-prepared meals was lower in young adults than in older adults. Nevertheless, reductions in intake achieved solely through lowering salt in processed foods would be limited because salt added in home-prepared meals still accounts for ~50% of the total dietary intake in Japan.[7] In fact, those who prefer salty taste frequently use salt at the table and salt concentrations in their miso soup were higher than those of others.[24] Taken together, these findings indicate that salt reduction strategies in Japanese populations should have two separate aspects, and these should be advanced together. For individuals, the previous campaign to raise awareness and modify behavior for salt reduction should be reintroduced. In particular, programs should aim to reduce added salt in home cooking and to specifically target the person who takes the role of family cook. In this study, salt intake among participants who were living with a spouse was significantly higher compared with other participants (Table 3). This result suggests that participants without a spouse might be younger and have less opportunity to eat traditional Japanese-style food than those with a spouse. Alternatively, the result may suggest that the saltiness of home-

Table 3 Population- and individual-level variance of estimated sodium intake with stepwise adjustment for individual-level characteristics by multilevel regression models[a]

	Men (n = *1027*)				*Women* (n = *1046*)			
	Model 0	*Model 1*	*Model 2*	*Model 3*	*Model 0*	*Model 1*	*Model 2*	*Model 3*
Individual-level variables	Regression coefficient and [95% confidence interval]				Regression coefficient and [95% confidence interval]			
Intercept	204.8 [198.8, 210.2][b]	118.5 [76.3, 160.7][b]	109.8 [66.4, 153.1][b]	98.8 [53.4, 144.2][b]	155.7 [149.9, 161.4][b]	99.7 [67.4, 131.9][b]	92.5 [59.5, 125.4][b]	87.5 [52.1, 123.0][b]
Age, years		0.4 [0.1, 0.6][b]	0.4 [0.1, 0.7][b]	0.2 [−0.1, 0.5]		−0.2 [−0.4, 0.04][c]	−0.1 [−0.4, 0.1]	−0.2 [−0.5, 0.05]
Body mass index, kg m^{-2}		3.8 [2.7, 4.9][b]	4 [2.8, 5.1][b]	4 [2.9, 5.1][b]		3.9 [3.0, 4.8][b]	4.1 [3.2, 5.0][b]	4.1 [3.2, 5.0][b]
Physical activity level, MET × h		−0.5 [−1.1, 0.1][c]	−0.4 [−1.0, 0.2]	−0.4 [−1.0, 0.2]		−0.6 [−1.1, −0.06][b]	−0.6 [−1.1, −0.04][b]	−0.5 [−1.1, 0.003][c]
Hypertension, yes (ref = no)			−7.1 [−18.4, 4.1]	−7.6 [−18.8, 3.5]			−6.4 [−18.0, 5.1]	−6.9 [−18.6, 4.8]
Hyperlipidemia, yes (ref = no)			0.2 [−11.8, 12.1]	−0.6 [−12.4, 11.3]			0.2 [−11.2, 11.6]	0.7 [−10.8, 12.1]
Diabetes, yes (ref = no)			−0.2 [−22.6, 22.2]	−4.6 [−27.4, 18.3]			−55.1 [−85.9, −24.3][b]	−54.5 [−85.3, −23.6][b]
Smoking (ref = no)								
Former				0.3 [−9.0, 9.5]				4.9 [−4.8, 14.7]
Current				−5.8 [−14.3, 2.7]				−6.6 [−14.9, 1.8]
Education (ref = university or equivalent)								
Junior college or equivalent				−3.5 [−12.2, 5.3]				−3.8 [−12.8, 5.3]
High school				−7.5 [−16.8, 1.8]				−3.3 [−13.1, 6.5]
Junior high school and other				23.7 [0.02, 47.5][b]				−14.9 [−30.7, 0.9][c]
Living status (ref = no)								
Living alone, yes				9.7 [−4.6, 24.1]				6.2 [−4.0, 16.5]
Living with spouse, yes				10.2 [0.7, 19.8][b]				7.3 [0.2, 14.4][b]
Food intake, g per 1000 kcal per day								
Bread				−0.2 [−0.4, 0.06]				−0.07 [−0.3, 0.1]
Noodle				0.2 [0.1, 0.3][b]				0.003 [−0.1, 0.1]
Miso soup				0.09 [0.03, 0.15][b]				0.06 [0.004, 0.11][b]
Pickled vegetable				0.5 [−0.01, 1.1][c]				0.2 [−0.2, 0.6]
Fish				−0.06 [−0.2, 0.1]				0.1 [−0.04, 0.2]
Dairy products				−0.005 [−0.08, 0.07]				-0.02 [-0.08, 0.04]
Variance								
Population-level variance	38.4	34.3	36.9	24.8	49.5[c]	51.1[c]	52.3[c]	41.6[c]
Individual-level variance	3506.7[b]	3316.4[b]	3315.0[b]	3228.4[b]	2572.2[b]	2404.3[b]	2383.8[b]	2366.7[b]
Intra-class correlation coefficient (ICC)[d]	0.01	0.01	0.01	0.008	0.02	0.02	0.02	0.02

Abbreviation: MET, metabolic equivalent.
[a]Model included estimated individual sodium excretion (mmol per day) as dependent variable.
[b]Statistical significance based on 95% confidence interval ($P<0.05$).
[c]Marginal association based on $P<0.10$.
[d]Intra-class correlation coefficient (ICC) = population-level variance/(population-level variance+individual-level variance).

prepared meals is likely based on salty taste preferences of particular family members. Moreover, the encouragement of food choices with consideration to up-to-date major dietary sources of sodium would serve to inform others who do not cook. In contrast to campaigns for individuals, a social movement aimed at shifting the distribution of processed foods by the food industry to low-salt foods would be effective in reducing intake in populations with high sodium intake and small within-country variation.

We examined the cause of the small within-country variation in sodium excretion. This examination was necessarily tentative because the variation was extremely small but not completely zero. Although several population-level variables (for example, demography, industry, economics, environments and dietary characteristics) were examined to explain small within-country variations in salt intake, we did not observe a meaningful relationship between them (data not shown). A further dietary survey is needed to explain the within-country variation of salt intake. Because the results of present study suggested an existence of negligible small within-country variations in salt intake, salt reduction in Japan can be most effectively achieved by a common nationwide strategy rather than through the targeting of regional differences in dietary habits.

Furthermore, despite the small within-country variation in sodium excretion, sodium excretion in the overall population was still high compared with other countries.[4] This result suggests that high sodium excretion might be attributable to common dietary characteristics and/or environments for the entire population of Japan. Additional detailed analyses based on international cooperative studies, such as Intersalt[25] and Intermap,[8,26] would shed light on dietary problems that are insufficiently recognized by the Japanese. Moreover, our urinalysis-based monitoring method for salt intake is useful for assessing the effectiveness of salt reduction owing to its greater feasibility than 24 h urine collection and availability, even for large-scale community settings.[16,27] Further research based on these approaches would provide useful evidence for overcoming the sluggish rate of salt reduction in Japan.

To our knowledge, this study is the first to identify the within-country variation in sodium intake estimated by urinalysis in all 47 prefectures of Japan. Most studies of the relationship between dietary intake and socioeconomic-dependent regional characteristics have been conducted in the United States and Europe.[13,14,28,29] Our results showed small within-country variation in sodium excretion, suggesting that socioeconomic-dependent regional characteristics may not yet have a remarkable impact in Japan, at least with regard to sodium intake. Regarding individual-level relationships, our results are consistent with the report by Asakura *et al.*,[6] which showed that sodium excretion is high in men and in participants with a greater BMI. In addition, the relationship between low education status and high sodium excretion is consistent with a similar analysis conducted in the United Kingdom.[13]

Our study has several strengths. First, we included all 47 prefectures of Japan, and participants were managed such that each sex and five 10-year age groups (20–60s) included the same number of participants in each prefecture.[16] Our study results based on this design will help to develop effective salt reduction strategies in Japan. Next, as a benefit of our multilevel analysis, we were able to take account of individualistic and ecological fallacy in this study.[30]

However, several limitations should also be mentioned. First, neither the study participants nor study facilities in each prefecture were a random sampling. Confirming the reliability of our results would require a further nationwide epidemiologic study in representative populations. Although our participants represented a convenience sample, the study population had similar characteristics for BMI and smoking status as NHNS-2013 (BMI, 23.6 kg m^{-2} in men and 22.1 kg m^{-2} in women aged 20–69 years; percentage of smokers, 30.2% in men and 7.2% in women).[17] In addition, because participants were only workers (and some of their family) in Japanese welfare facilities, the estimated sodium excretion and the association with other variables should be carefully interpreted. Further studies that include participants in various socioeconomic statuses are required. Second, sodium excretion was estimated by the 'spot urine' method,[16] whose accuracy for salt intake at the individual level was confirmed to be poor to moderate.[16] Although we excluded participants with very low or high sodium excretion as outliers, the individual-level variance in sodium excretion in this study included variance from measurement error. Nevertheless, the population average of estimated sodium excretion in this study was consistent with sodium excretion estimated by two 24 h urine collections in a previous study conducted in 2013.[6] Third, our adjustment of individual characteristics was insufficient. Because of characteristics of the BDHQ, individual seasoning (for example, soy sauce) intake was not examined in the present analysis, but we examined most other foods that are major sources of salt. Further surveys would be needed to explore the within-country variation and its causes in salt intake among the Japanese population. Finally, we assumed that participants were affected only by the region in which they lived. Although we confirmed that almost participants had lived in their prefecture for 20 or more years, participants living near the boundaries of several regions may have been affected by different population-level characteristics, suggesting that variations in sodium excretion between several adjacent regions might be attenuated by these participants. Smaller levels of regional categories (for example, city, town, and so on) and more detailed modeling of geographical effects using a geographical information system might be potential solutions to this problem.[31]

CONCLUSION

Although an apparent North–South variation in sodium intake was identified, the population-level variance in sodium excretion was extremely small in Japan. To effectively reduce salt consumption in Japan, a common nationwide strategy would be more suitable than any focus on regional differences in dietary habits regarding salt intake.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Supplementary Information accompanies the paper on Hypertension Research website (http://www.nature.com/hr)