Estimated dietary sodium intake in Thailand: A nationwide population survey with 24-hour urine collections

Worawon Chailimpamontree MD, MHSc1,2 | Surasak Kantachuvesiri MD, PhD2,3 | Wichai Aekplakorn MD, PhD4 | Raweewan Lappichetpaiboon B.Sc, M.Sc2,5 | Nintita Sripaibooknij Thokanit MPH, DrPH6 | Prin Vathesatogkit MD, PhD7 | Ananthaya Kunjiang B.P.H, M.Sc2 | Natthida Boonyagarn B.Sc, M.Sc2 | Penmat Sukhonthachat M.Sc, Dr.P.H8 | Narinphop Chuaykarn B.H.E, M.Sc.9 | Patthrapon Sonkhhamme B.P.H, M.Sc10 | Payong Khunsaard B.Sc, M.P.H11 | Phassakon Nuntapanich M.Sc, Ph.D12 | Pattarapol Charoenbut M.Sc, Dr.P.H13 | Comsun Thongchai B.Sc, M.P.H13 | Apinya Uttarachai B.Sc, M.P.H.14 | Wisrut Kwankhoon B.Sc, M.Sc15 | Fuangfah Rattanakanahutanon B.Sc, M.P.H14 | Krich Ruangchai B.Sc, M.P.H14 | Nadchar Yanti B.Sc, B.P.H, M.Sc14 | Natnapa Sasang B.N.S, M.P.H16 | Sushera Bunluesin PhD17 | Renu Garg MD, MPH17

1Division of Nephrology, Department of Medicine, Chandrubeksa hospital, Nakhon Pathom, Thailand
2Thai low salt network, Nephrology Society of Thailand, Bangkok, Thailand
3Division of Nephrology, Department of Medicine, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand
4Department of Community Medicine, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand
5Department of Nutrition, Fort Nawamintharachini Hospital, Chon Buri, Thailand
6Ramathibodi Comprehensive Cancer Center, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand
7Division of Cardiology, Department of Medicine, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand
8Faculty of Science and Technology, Songkhla Rajabhat University, Songkhla, Thailand
9Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, Thailand
10Chiang Rai Provincial Health office, Ministry of Public Health, Thailand
11Faculty of Public Health, Chiang Rai College, Chiang Rai, Thailand
12Ubon Ratchathani Rajabhat University, Ubonratchathani, Thailand
13Faculty of Public Health, Ubon Ratchathani Rajabhat University, Ubon Ratchathani, Thailand
14Faculty of Public Health, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
15Faculty of Science and Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
16Faculty of Public Health, Phranakhon Si Ayutthaya Rajabhat University, Phra Nakhon Si Ayutthaya, Thailand
17WHO Country Office for Thailand, Bangkok, Thailand

Abstract
Thailand has committed to reducing population sodium intake by 30% by 2025. However, reliable nationally representative data are unavailable for monitoring progress toward the goal. We estimated dietary sodium consumption using 24-hour
1 | INTRODUCTION

High intake of sodium was the leading dietary risk factor associated with 3 million deaths and 70 million disability-adjusted life-years (DALYs) lost in 2017, worldwide. Excess sodium consumption is associated with raised blood pressure and increased cardiovascular risk and chronic kidney disease. The World Health Organization recommends limiting daily sodium intake to less than 2000 mg to reduce the risk of hypertension and associated cardiovascular disease.

Cardiovascular disease was responsible for an estimated 145,000 deaths or 29% of all deaths in Thailand in 2016. Stroke and ischemic heart disease have consistently ranked as the top two causes of mortality in Thai population during the past decade. Of concern, the prevalence of hypertension has steadily increased from 21% in 2003 to 25% in 2014. Recognizing the high and rising burden of cardiovascular disease, the National Health Assembly in 2015 adopted a resolution committing to reduce sodium consumption in Thai population by 30% by 2025. Subsequently, a multipronged national sodium reduction strategy was developed to achieve this goal.

Regular monitoring with valid data is critical for tracking the progress in sodium reduction efforts. Available studies on sodium consumption in Thailand are not nationally representative in scope or have methodological limitations. One nationwide study used a 7-day dietary recall in combination with weighing household condiments and estimated the daily intake at 10.8 grams of salt (4320 mg sodium). Another national-level survey using food frequency questionnaire found that daily sodium consumption varied from 2473 mg among children (aged 1-5 years) and 3265 mg per day among adults. Both studies used indirect methods and are likely to underestimate sodium consumption. Studies using 24-hour urinary analyses are considered to provide more accurate measurement of sodium intake. Limited number of Thai studies has been conducted using 24-hour urine collections, and these were in a small sample of high-risk patients, unrepresentative and unreliable for a national benchmark.

To provide robust data for monitoring the progress toward the national sodium reduction target, this study aims to estimate dietary sodium intake using 24-hour urine collection methodology from a representative nationally drawn sample. The study also describes variations in sodium intake by geographical regions and examines factors associated high sodium consumption.

2 | METHODS

2.1 | Study design and participants

This was a nationwide, population-based cross-sectional survey using 24-hour urine collections. The survey was conducted between April 2019 and May 2020. We included both urban and rural areas in four Regions of Thailand (North, South, North-east, Central) plus the Bangkok metropolitan area to represent the entire country. Study participants included adults aged 18 years and older who were eligible and provided informed consent. Participants were excluded if they: had a known history of end-stage renal disease; started diuretic within the previous 2 weeks; were pregnant, breastfeeding, or menstruating; refused to provide consent; used salt supplements, and sodium retaining medicines; or were on steroid therapy.

2.2 | Sampling and sample size

We calculated the sample size for estimating population mean using the software, N4studies. We assumed the standard deviation of sodium intake to be 3.8 g/d based on a previous report of an estimated variation of mean sodium intake in Thai population. We used an effect size of 0.21 and significance level (alpha) of 0.05, to calculate the required sample size to be 250 for each of the eight strata, that is, men and women in four age groups (18-29, 30-44, 45-59, 60 and above).
To account for the possibility of 20 percent refusal to participate, we adjusted the total expected sample size to 2400.

There are 76 provinces in 13 Health Service Areas in 4 geographic Regions of Thailand. We used multi-stage stratified-cluster random sampling to select participants. First, in each of the four geographic Regions of Thailand, we randomly selected two to three provinces, one province from each Health Service Area. A total of 13 provinces and Bangkok metropolitan area were selected. Secondly, for each province, we randomly selected two districts, one urban and one rural. Thus, in total, 28 districts in 14 provinces were selected. Finally, patients in each sampled district were randomly selected from eight strata, stratified by sex and four age groups: 18-29, 30-44, 45-59, 60 and above. Updated population registries maintained by district health office were used for the sampling universe, and samples were proportionally drawn from each strata.

2.3 | Data collection

In each region, a multidisciplinary team was trained to collect demographic, anthropometric, and clinical data as well as 24-hour urine specimens from all consenting participants.

2.3.1 | Demographic and clinical data

A structured questionnaire was used to collect data on age, sex, occupation, education level and income, medical history, and current medication consumed.

2.3.2 | Physical measurements

Height was measured to the nearest 1 centimeter. Weight was measured using calibrated Tanita HD-380 portable electronic scales (USA) to the nearest 100 grams. Body mass index (BMI) was calculated by dividing weight in kilograms by height in meters squared (kg/m²). Blood pressure was measured using a digital blood pressure device, Omron HEM-7130-L (Omron Healthcare). Participants were asked to rest for 15 minutes before measurement. Blood pressure was measured 3 times at 15-minute intervals. The first measurement was discarded, and an average of the last two readings was used. Hypertension was defined as anyone with systolic blood pressure ≥ 140 and or diastolic blood pressure ≥ 90 mm Hg or taking medication for hypertension.

2.3.3 | Urine Collection

Field researchers provided each participant with detailed verbal and written instructions using a pictorial guide. Each participant received a labeled sterile plastic container of 5-Liter capacity.

### Table 1: Characteristics of study participants who did not complete 24-hour urine collection

| Characteristics                        | Total number | Did not complete Number | %   |
|----------------------------------------|--------------|--------------------------|-----|
| Overall                                | 2388         | 789                      | 33.0|
| Region **                              |              |                          |     |
| Bangkok                                | 398          | 234                      | 58.8|
| Central                                | 496          | 172                      | 34.7|
| North                                  | 496          | 164                      | 33.1|
| Northeast                               | 498          | 156                      | 31.3|
| South                                  | 500          | 63                       | 12.6|
| Area**                                 |              |                          |     |
| Urban                                  | 1158         | 461                      | 39.8|
| Rural                                  | 732          | 172                      | 23.5|
| Sex**                                  |              |                          |     |
| Male                                   | 1162         | 414                      | 35.6|
| Female                                 | 1226         | 375                      | 30.6|
| Age groups **                          |              |                          |     |
| 18-29 years                            | 571          | 198                      | 34.7|
| 30-44 years                            | 606          | 170                      | 28.1|
| 45-59 years                            | 655          | 201                      | 30.7|
| 60 years and above                     | 554          | 218                      | 39.4|
| Education level**                     |              |                          |     |
| Primary                                | 828          | 305                      | 36.8|
| Secondary and above                    | 1484         | 458                      | 30.9|
| Income (Thai baht per month)**         |              |                          |     |
| Low (0-9,999)                          | 1654         | 506                      | 30.6|
| Medium (10,000-19,999)                 | 466          | 187                      | 40.1|
| High (20,000 and above)                | 181          | 66                       | 36.5|
| Body mass index (Kg/m²)**              |              |                          |     |
| <18.5                                  | 205          | 104                      | 50.7|
| 18.5-24.9                              | 1245         | 475                      | 38.2|
| 25 and above                           | 868          | 187                      | 21.5|
| Hypertension*                          |              |                          |     |
| Yes                                    | 695          | 221                      | 31.8|
| No                                     | 1628         | 545                      | 33.5|
| History of diabetes **                 |              |                          |     |
| Yes                                    | 195          | 83                       | 42.6|
| No                                     | 2128         | 683                      | 32.1|
| Marital status                         |              |                          |     |
| Married                                | 1341         | 419                      | 31.2|
| Single                                 | 672          | 243                      | 36.2|
| Separate/Divorce/Other                 | 309          | 103                      | 33.3|

*Hypertension was defined as anyone with systolic blood pressure ≥ 140 and or diastolic blood pressure ≥ 90 mm Hg or taking medication for hypertension.

**p-value < 0.05 when compared with participants who completed urine collection.
measuring cups, a cooler box, and a time sheet for recording the time and volume of urine collection. On the morning of the collection day, participants were instructed to discard the first morning urine specimen after waking up. Participants were asked to note the exact time of the first collection, and each collection subsequently. Participants were asked to collect all urine specimens over the next 24 hours, starting with the second void and including the first void on the following day. Participants were instructed to store all urine specimens in the 5-Liter cooler box filled with ice and record the time and volume of urine at each void. In case of reported duration of collection of 1 void was missed, or if there was more than one episode of substantial spillage of a void, the collection was deemed incomplete and the participant was offered to redo the 24-hour collection.

**2.4 | Processing of urine samples**

Urine samples were collected by trained field researchers on the day of completion and transferred to the local laboratory for determination of urine volume, sodium, potassium, and creatinine excretion. The volume was standardized to 24-hour period as follows: (total volume collected in liters/self-reported collection time in hours) times 24 hours.

Urinary sodium and potassium were determined using the indirect ion-selective electrode method and the enzymatic method for urine creatinine assay. Urine samples were considered incomplete if (a) total urine volume was less than 500 ml in 24-hour collection; (b) estimated daily urinary creatinine excretion was less than 0.98 g/day for males and less than 0.72 g/day for females; (c) reported duration of

| TABLE 2 | Characteristics of participants who completed 24-hour urine collection, by Regions |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Characteristics | Total N (%)     | Bangkok N (%)   | Central N (%)   | North N (%)     | Northeast N (%) | South N (%)     | p-value         |
| Overall         | 1599            | 164 (10.3)      | 324 (20.3)      | 332 (20.8)      | 342 (21.4)      | 437 (27.3)      | .253            |
| Sex             |                 |                 |                 |                 |                 |                 |                 |
| Female          | 851 (53.2)      | 88 (53.7)       | 186 (57.4)      | 181 (54.5)      | 181 (55.9)      | 215 (49.2)      |                 |
| Region          |                 |                 |                 |                 |                 |                 | <.001           |
| Urban           | 849 (53.1)      | 164 (100)       | 165 (50.9)      | 151 (45.5)      | 152 (46.9)      | 217 (49.7)      |                 |
| Age groups      |                 |                 |                 |                 |                 |                 | .014            |
| 18-29 years     | 373 (23.3)      | 38 (23.2)       | 53 (16.4)       | 82 (24.7)       | 92 (28.4)       | 108 (24.7)      |                 |
| 30-44 years     | 436 (27.3)      | 52 (31.7)       | 93 (28.7)       | 89 (26.8)       | 95 (29.3)       | 107 (24.5)      |                 |
| 45-59 years     | 454 (28.4)      | 37 (22.6)       | 118 (36.4)      | 90 (27.1)       | 87 (26.9)       | 122 (27.9)      |                 |
| 60 years and above | 336 (21) | 37 (22.6)       | 60 (18.5)       | 71 (21.4)       | 68 (21)         | 100 (22.9)      |                 |
| Education Level |                 |                 |                 |                 |                 |                 | .004            |
| Secondary and above | 1026 (66.2) | 117 (71.3)      | 195 (60.2)      | 201 (60.5)      | 206 (63.6)      | 307 (70.2)      |                 |
| Income (Thai baht per month) |         |                 |                 |                 |                 |                 | <.001           |
| Low (0-9999)    | 1148 (74.4)     | 88 (53.7)       | 219 (67.6)      | 284 (85.5)      | 233 (71.9)      | 324 (74.1)      |                 |
| Medium (10 000-19 999) | 279 (18.1) | 52 (31.7)       | 79 (24.4)       | 37 (11.1)       | 29 (9)          | 82 (18.8)       |                 |
| High (20 000 and above) | 115 (7.5) | 23 (14)         | 24 (7.4)        | 11 (3.3)        | 26 (8)          | 31 (7.1)        |                 |
| Body mass index (Kg/m²) |         |                 |                 |                 |                 |                 | .005            |
| <18.5           | 101 (6.5)       | 18 (11)         | 21 (6.5)        | 22 (6.6)        | 12 (3.7)        | 28 (6.4)        |                 |
| 18.5-24.9       | 770 (49.6)      | 97 (59.1)       | 159 (49.1)      | 151 (45.5)      | 155 (47.8)      | 208 (47.6)      |                 |
| 25 and above    | 681 (44.0)      | 49 (29.9)       | 144 (44.4)      | 159 (47.9)      | 128 (43.4)      | 201 (46)        |                 |
| Hypertension*   |                 |                 |                 |                 |                 |                 | <.001           |
| Yes             | 474 (30.4)      | 48 (29.3)       | 113 (34.9)      | 111 (33.4)      | 60 (18.5)       | 142 (32.5)      |                 |
| History of diabetes |         |                 |                 |                 |                 |                 | .584            |
| Yes             | 112 (7.2)       | 14 (8.5)        | 29 (9)          | 21 (6.3)        | 20 (6.7)        | 28 (6.4)        |                 |
| Marital status  |                 |                 |                 |                 |                 |                 | .001            |
| Married         | 922 (59.2)      | 76 (46.3)       | 186 (57.4)      | 201 (60.5)      | 193 (59.6)      | 266 (60.9)      |                 |
| Single          | 429 (27.6)      | 63 (38.4)       | 77 (23.8)       | 94 (28.3)       | 75 (23.1)       | 120 (27.5)      |                 |
| Separate/Divorce | 206 (13.2)    | 25 (15.2)       | 61 (18.8)       | 37 (11.1)       | 32 (9.9)        | 51 (11.7)       |                 |

*Hypertension was defined as anyone with systolic blood pressure ≥ 140 and or diastolic blood pressure ≥ 90 mm Hg or taking medication for hypertension. Bold significance are P-value <0.05.
collection was less than 24 hours; (d) more than 1 void was reported as missed; or (e) there was > 1 episode of significant spillage of a void.

2.5 | Statistical analysis

We analyzed data with sample weighted against the Thai population registry 2019. Probability weights were the inverse of the calculated probability of sampling of individuals in each region, province, area of residence (urban/rural), sex, and 4 age groups. Weighted mean, standard deviation, 95% confidence interval (CI) of mean, and median and interquartile range (IQR) were calculated for continuous variables. We compared the weighted mean of sodium intake by sex, region, urban/rural residence, education level, and presence of hypertension or diabetes using t test, and ANOVA, as appropriate. Chi-square test and Fisher’s exact test were used to compare categorical variables. Multivariate logistic regression analysis was performed to examine association between high sodium consumption (≥ 2000 mg per day) with sex, region, urban/rural residence, education level, occupation, marital status, family income, BMI, hypertension, and diabetes. Multivariate linear regression analysis was also performed to examine association between weighted mean of sodium consumption with the same variables as multivariate logistic regression. A two-side p-value < .05 was considered statistically significant. Adjusted odds ratio (AOR) and 95% CI were calculated. Statistical analysis was performed using Stata Corp Stata 15.1 v.2020.

3 | RESULTS

3.1 | Population characteristics

Of 2400 sampled participants, 2388 consented to participate in the study and provided a 24-urine specimen. Among these, 1599 participants (67%) completed a 24-hour urine collection, significantly high proportion of participants who did not complete urine collection in Bangkok (59%); this proportion was the lowest in the South (13%) (Table 1). Urine completion rate was lowest in urban areas, among elderly males with lower education level, median monthly income, underweight, or diabetes. Among those with complete urine collection, the mean age was 44.3 years (range 18-85 years) and 53% were female. Majority (66%) had above secondary level of education. In all, 30% had hypertension, 44% were overweight or obese, and 7.2% had a history of being diagnosed with diabetes previously. Characteristics of study population across regions showed some variations in socio-demographic variables (Table 2). Also, the North-east Region had a significantly lower proportion of hypertensive population and Bangkok had the lowest proportion of overweight and obese population.

3.2 | Weighted mean 24-hour urinary sodium excretion by regions

Overall weighted mean 24-hour sodium excretion in Thailand was 3305 mg (Table 3). Sodium excretion was highest in the South.
### TABLE 3

Weighted estimated 24-hour urinary electrolyte excretion, by Regions

| Region         | Salt intake (g/day) | Estimated sodium consumption (mg/24h) | Urine Na/K ratio (mmol/mmol) | Sodium creatinine ratio (Molar ratio) | Urine creatinine excretion (mg/24h) | Volume (ml) |
|----------------|--------------------|-------------------------------------|-----------------------------|-------------------------------------|-------------------------------------|-------------|
| North          | 1245 (935-1920)    | 1846.4 (874.1)                      | 5 (2.4)                     | 1.3 (0.6)                            | 1285.7 (401.9)                      | 1757.1 (954.6) |
| North-east     | 1276.2 (1035.5-1552.2) | 1189.7 (330.6)                      | 4.5 (3.3-6.1)               | 1.2 (0.9-1.6)                        | 1143.1 (869.2-1488.4)              | 1530 (1030-2330) |
| North-east     | 3127.8 (2373.5-3994) | 3238.8 (1727.6)                      | 4.7 (1.8)                   | 1.3 (0.9-1.8)                        | 3127.8 (1030-2330)                | 1416.8 (752.6) |
| South          | 1070 (759.4-1467.3) | 1157 (433.3)                         | 5.1 (3.7-6.9)               | 1.2 (0.9-1.6)                        | 3440.5 (2610.8-4393.3)            | 2250 (935-1467.3) |
| North          | 8.6 (6.5-10.9)     | 8.9 (4.7)                            | 8.0 (5.7-11.4)              | 1.2 (0.9-1.6)                        | 3440.5 (2610.8-4393.3)            | 2250 (935-1467.3) |

### DISCUSSION

The first nationally representative population-based survey in Thailand using 24-hour urine collection methodology indicated that the average urinary sodium excretion was 3305 mg/day. Applying the evidence that about 90% of the sodium consumed is excreted in urine, the mean dietary sodium intake in Thai population in 2019-2020 was estimated to be 3636 mg/day (equivalent to salt intake of 9.1 g/day).

Dietary sodium intake in the Thai population is nearly twice the amount recommended by WHO. High sodium consumption in the population is attributed to the generous use of condiments and seasonings while cooking and at the table. Earlier studies have indicated that approximately 90% of dietary sodium comes from condiments such as fish sauce, soy sauce, salt, and seasoning cube. In addition, monosodium glutamate or MSG is commonly used in most Thai recipes for its Umami flavor. Moreover, the use of packaged and ready to eat food such as instant noodles, frozen foods, all high in sodium is also population and on the rise.

When adjusted for available confounding factors as shown in Table 4, participants from the Southern Region (AOR: 3.53, 95% CI 1.91-6.53; p = .000) and Central Region (AOR: 2.32, 95% CI 1.31-4.13; p = .004) were more likely to consume excess sodium > 2000 mg per day compared with Bangkok. Higher sodium consumption was independently associated with younger age groups (18-29 years) (AOR 2.81, 95% CI: 1.53-5.17; p = .001); 30-44 years (AOR 2.09, 95% CI: 1.21-3.61; p = .008); higher education (AOR 1.79; 95% CI: 1.19-2.67; p = .005); BMI ≥ 25 (AOR 1.55; 95% CI 1.09-2.21; p = .016); and hypertension (AOR 1.58; 95% CI 1.02-2.44; p = .038). No significant association was noted between sodium consumption and sex, residential area, monthly income, or history of diabetes (p > .05). We also found that results from multivariate linear regression using mean sodium consumption were consistent with those from multivariate logistic regression (data not shown).
Interestingly, estimated sodium intake in Thailand was lower than in its Asian neighbors: India (3720 mg/d in Delhi and 4098 mg/day in Andhra Pradesh); South Korea (3960 mg/day); China (4349 mg/day); Nepal (5280 mg/day); and Bangladesh (6800 mg/day).\(^{26-30}\) Whether the comparatively lower estimates found in this study reflect a recent declining trend in Thailand cannot be stated with certainty due to the lack of previous studies using 24-hour urine collections. While the results of this survey can be generalized to Thailand owing to the large and representative sample of the study, the findings may not be applicable directly to other Asian countries due to significant differences in dietary patterns among countries. Future surveys are necessary on a nationally representative sample using similar methodology to infer conclusively about trends in sodium consumption in the Thai population.

Sodium intake was above 3000 mg in all areas, although significant variations were noted across Regions. Sodium intake was highest in the South Region followed by Central Region. According to available information, the top three condiments contributing to dietary sodium in the South Region are salt, fish sauce, and shrimp paste.\(^{31}\) Anecdotally, several cultural practices related to cooking, processing, and consumption patterns may also play a role in higher sodium intake in the South Region. First, seafood is the staple diet in the South due to its proximity to the coast; majority of popular seafood dishes including shellfish and octopus have notably high sodium content. Second, preservation of seafood with salt is a routine practice during food processing and cooking. Third, in addition to regular condiments, the southern diet includes a special spicy shrimp paste and fish sauce (Buda) which contains high amount of sodium (4751 mg sodium per 100 gm). The high sodium intake in the Central Region could be due to the large population of factory workers who usually consume most meals outside home. Surprisingly, sodium consumption was the lowest in the north-east Region even though available studies indicate that consumption of fermented fish high in sodium is quite common in this Region. As data in the North-east Region were collected during COVID-19, it is possible that dietary habits may have temporarily changed during a time of a crisis. Quantitative and qualitative study are needed to better understand dietary patterns responsible for differences in sodium consumption in the different Regions of Thailand and devise customized communication strategies to support communities for reducing sodium consumption.

Our study shows that higher sodium intake (above 2000 mg/day) was independently associated with hypertension, overweight and obesity, higher education, and younger age group. An earlier national survey also found that sodium intake was higher sodium among younger population\(^ {11}\) which may explained partly due to higher caloric intake and consumption of fast food among young people.\(^ {32,33}\) There is growing empirical evidence in support of a positive relationship between sodium intake and BMI\(^ {34-36}\) which may result from increased consumption of sugar-sweetened beverages\(^ {32,37}\) and calorie dense fast food.\(^ {38}\) High salt intake is also reported to be associated with greater deposition of subcutaneous abdominal adipose tissue and body fat.\(^ {39,40}\) The evidence of a positive association between BMI and salt intake in our study and other studies underscores the importance of addressing behavioral and metabolic risk factors through comprehensive multipronged strategies. Such comprehensive efforts comprising engagement with food industry for reformulation, introduction of front-of-pack warning labels, increasing the availability of low sodium recipes in schools and workplace settings, and restricting marketing of unhealthy food and beverages in conjunction with mass public awareness campaigns have led to an extensive decrease in energy, total sugar, and sodium content for the most frequently consumed packaged food products in Chile\(^ {41}\) and a 24% reduction in dietary sodium consumption in South Korea.\(^ {42}\) Similar approaches are needed in Thailand.

Consistent with other studies, our study demonstrated a significant positive relationship between high sodium intake and hypertension.\(^ {43,44}\) Increased sodium sensitivity is cited as a possible reason for higher consumption among hypertensive patients.\(^ {45}\) Thailand has a high prevalence of raised blood pressure with an estimated 13.2 million estimated to have hypertension.\(^ {7}\) Currently, 7 million patients are registered for treatment for hypertension and have regular contact with a public health facility once in three months.\(^ {46}\) These encounters can be used as opportunities to offer nutrition counseling for sodium reduction both to patients and to their relatives. Intervention research should be undertaken to assess the effectiveness and impact of different nutrition counseling strategies on sodium consumption and blood pressure control among patients with hypertension.

In addition to high sodium intake, an imbalanced diet with low potassium consumption is also an important determinant of raised blood pressure.\(^ {43,47}\) The WHO recommends a minimum daily intake of 3,510 mg of potassium and a 1:1 sodium to potassium (Na/K) ratio.\(^ {48}\) The mean urinary potassium excretion in this study was 1,221 mg/d (30% of the recommendation), while the mean Na/K molar ratio was five times the WHO recommended level. Although urinary potassium excretion is an uncertain indicator of dietary potassium intake,\(^ {49}\) given the high prevalence of hypertension in Thailand\(^ {51}\) strategies should be considered to reduce sodium and increase potassium intake. Apart from public awareness campaigns and fiscal policies to promote fruits and vegetables, salt substitutes containing potassium chloride can be a potentially important strategy to reduce sodium and increase potassium intake, thereby lowering blood pressure.\(^ {50}\) Additionally, there is a need to study the feasibility, acceptability, safety, and cost-effectiveness of introducing potassium enriched sodium substitutes in Thai population.

Our study has several strengths. This large population-based survey in adult men and women across several age groups draws sample from both urban and rural areas in 13 out of 76 provinces of Thailand. Almost all participants (except 12) agreed to participate in the study and provided a 24-hour urine specimen. High participation could be achieved in part due to the involvement of health volunteers who are highly trusted by communities. Additionally, a nominal financial incentive of 500 THB (15 USD) may have helped in recruitment of participants. Despite using stringent criteria for exclusion, the net response rate was as high as 67% which is comparable or higher than other studies.\(^ {23,26}\) Although implementation of a large
nationwide, field-based survey using 24-hour urine collections was resource intensive and logistically challenging, it contributed to build institutional capacity in the capital and four regions of the country. It also helped to establish a rigorous survey protocol which can be replicated for future monitoring.

The study also has some limitations. First, urine completion rates varied by population characteristics and were significantly lower in the Central Region. We were unable to adjust for these differences which may have skewed our findings toward producing an overall estimate influenced by populations that are over-represented in the study. Second, despite our best efforts to ensure complete urine collection, it is possible that some participants may not have provided complete urine collections. We overcame this limitation to a great extent by using stringent and objective inclusion criteria based on urine volume and creatinine excretion. Yet it is possible that some specimens may have been incomplete. Further analysis excluding those potentially incomplete specimens did not substantially change the estimates. Based on these analyses, we believe that the overall impact of the incomplete urine collection in our study is that it resulted in underestimating sodium and potassium excretion.

Third, although we weighted our data to account for sampling probability based on age structure of each area, it was not possible to adjust for all potential confounders. Finally, although we aimed to collect urine specimens on all days of the week, most participants...
provided specimens on weekends. Eating patterns on weekends can be variable—working population may prefer to eat at home whereas others may prefer to go out on weekends. These eating patterns may have skewed sodium consumption estimates in our study in one or the other direction. It is important to take this into account while planning and implementing the next survey, so that urine collection protocol in the next round is as consistent as possible to the protocol implemented in this round.

5 | CONCLUSIONS

The first nationally representative population-based survey using 24-hour urinary analyses indicates that dietary sodium consumption among Thai adults is 3635 mg/day, about twice the amount recommended by WHO. These findings call for accelerating the implementation of multipronged interventions which are included in Thailand’s national sodium reduction strategy SALTS, namely (a) improving the quality of nutrition programmes in settings such as schools, workplaces and communities (S); (b) Public awareness (A); (c) legislation for to regulate sodium level in packaged food, effective front-of pack food labeling, and restriction on marketing of unhealthy foods (L); (d) use of innovation and technology to develop suitable sodium substitutes (T); and (e) regular surveillance (S). In contribution to the surveillance component of the SALTS strategy, our study provides a robust estimate for tracking progress toward population national sodium reduction goals. Better understanding is needed of reasons for higher sodium intake in Southern and Central Regions and among younger and more educated populations. Furthermore, combined and comprehensive action is needed to address clustering of multiple risk factors, viz, high sodium consumption, BMI ≥ 25kg/m² and hypertension. Surveys using consistent methodology conducted every 3-5 years should help to monitor progress and fulfill Thailand’s global commitments to prevent avoidable morbidity and premature mortality from cardiovascular disease.

ACKNOWLEDGMENTS

This analysis was supported by Bloomberg Philanthropies and Resolve to Save Lives, an initiative of Vital Strategies, through a grant to the National Foundation for the Centers for Disease Control and Prevention Inc (CDC Foundation). Resolve to Save Lives is funded by grants from Bloomberg Philanthropies; the Bill and Melinda Gates Foundation; and Gates Philanthropy Partners, which is funded with support from the Chan Zuckerberg Foundation. We would also like to acknowledge the support of the mentorship collaboration consisting of US Centers for Disease Control and Prevention, Resolve to Save Lives, World Hypertension League, and Lancet Commission on Hypertension Group. The authors wish to thank the staff and individuals in the communities who participated in the study. We would like to acknowledge the Thai Health Promotion Foundation, and WHO for providing funding and technical support of the study. Special thanks to Lawrence Appel, Mary Cogswell, Leanne Riley, Laura Cobb, and Dinesh Neupane for technical support. The authors are solely responsible for the design and conduct of this study, all analyses, the drafting of the manuscript, and its final content.

### TABLE 4
Factors associated with high sodium consumption (>2000 mg/day)

| Characteristics | Adjusted Odds Ratio | 95% CI       | p-value |
|-----------------|---------------------|--------------|---------|
| **Sex**         |                     |              |         |
| Female          | 1.00                |              |         |
| Male            | 1.11                | 0.80-1.54    | .545    |
| **Region**      |                     |              |         |
| Bangkok         | 1.00                |              |         |
| Central         | 2.32                | 1.31-4.13    | .004    |
| North           | 1.14                | 0.64-2.03    | .655    |
| Northeast       | 1.27                | 0.70-2.30    | .438    |
| South           | 3.53                | 1.91-6.53    | .000    |
| **Area**        |                     |              |         |
| Rural           | 1.00                |              |         |
| Urban           | 1.28                | 0.89-1.84    | .188    |
| **Age group**   |                     |              |         |
| 60 years and above | 1.00            |              |         |
| 45-59 years     | 1.22                | 0.78-1.90    | .387    |
| 30-44 years     | 2.09                | 1.21-3.61    | .008    |
| 18-29 years     | 2.81                | 1.53-5.17    | .001    |
| **Education level** |                 |              |         |
| Primary         | 1.00                |              |         |
| Secondary and above | 1.79            | 1.19-2.67    | .005    |
| **Income (Thai baht per month)** | |              |         |
| Low (0-9999)    | 1.00                |              |         |
| Medium (10-19 999) | 0.75          | 0.47-1.21    | .241    |
| High (20 000 and above) | 1.66    | 0.76-3.64    | .203    |
| **Body mass index (Kg/m²)** | |              |         |
| 18.5-24.9       | 1.00                |              |         |
| <18.5           | 0.72                | 0.36-1.42    | .338    |
| 25 and above    | 1.55                | 1.09-2.21    | .016    |
| **Hypertension** |                   |              |         |
| No              | 1                   |              |         |
| Yes             | 1.58                | 1.02-2.44    | .038    |
| **History of diabetes** | |              |         |
| No              | 1                   |              |         |
| Yes             | 1.20                | 0.63-2.27    | .583    |

*Hypertension was defined as anyone with systolic blood pressure ≥ 140 and or diastolic blood pressure ≥ 90 mm Hg or taking medication for hypertension. Bold significance are P-value <0.05.
CONFLICT OF INTEREST
None.

ORCID
Worawon Chailimpamontree https://orcid.org/0000-0001-7265-9873

REFERENCES
1. Afshin A, Sur PJ, Fay KA, et al. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2019;393(10184):1958-1972.
2. Grillo A, Salvi L, Coruzzi P, Salvi P, Parati G. Sodium Intake and Hypertension. Nutrients. 2019;11(9):1970.
3. Farquhar WB, Edwards DG, Jurkowitz CT, Weintraub WS. Dietary sodium and health: more than just blood pressure. J Am Coll Cardiol. 2015;65(10):1042-1050.
4. World Health O. Guideline: sodium intake for adults and children. Geneva: World Health Organization; 2012.
5. World Health O. Noncommunicable diseases country profiles 2018. Geneva: World Health Organization; 2018.
6. Institute for Health Metrics and Evaluation (IHME). Thailand profile. 2018; http://www.healthdata.org/Thailand. Accessed Sep 19, 2019.
7. World Health Organization. Country Office for T. Hypertension care in Thailand: best practices and challenges, 2019. Bangkok: World Health Organization. Country Office for Thailand; 2019.
8. 8th National Health Assembly. Agenda 2.4 : Policy on reduction of sodium intake and socio-demographic determinants of the non-compliance with daily sodium intake recommendations: Thai NHES IV. J Med Assoc Thai. 2013;96(Suppl 5):S161-170.
9. Sinawat S. Result of the survey. Survey report of sodium chloride intake of Thai population. Nonthaburi: Nutrition Division, Department of Health, Ministry of Public Health; 2009:59–64.
10. Satheannoppakao W, Kasemsup R, Inthawong R, et al. Sodium intake, socio-demographic determinants of the non-compliance from 24-hour urine samples and spot urine samples: a systematic review and meta-analysis. Int J Epidemiol. 2015;44(1):239-250.
11. Satheannoppakao W, Kasemsup R, Inthawong R, et al. Sodium in Thailand: best practices and challenges, 2019
12. McLean R. Measuring Population Sodium Intake: A Review of Methods. Nutrients. 2014;6:4651-4662.
13. Gemming L, Jiang Y, Swinburn B, Utter J, Mhurchu CN. Underestimation of Disease Study 2017.
14. Halpern BP. What’s in a Name? Are MSG and Umami the Same? Eur J Clin Nutr. 2014;68(2):259-264.
15. Campbell NRC, He FJ, Tan M, et al. The International Consortium for Quality Research on Dietary Sodium/Salt (TRUE) position statement on the use of 24-hour, spot, and short duration (<24 hours) timed urine collections to assess dietary sodium intake. J Clin Hypertens. 2019;21(6):700-709.
16. Peera Buranakitjaroen M, Phoijaroenchanachai M. The prevalence of high sodium intake among hypertensive patients at hypertension clinic, Siriraj Hospital. J Med Assoc Thai. 2013;96(2):S1-S8.
17. Ngunjarus C, Chongsuvivatwong V, McNeil E. n4Studies: Sample Size Calculation for an Epidemiological Study on a Smart Device. Siriraj Med J. 2016;68:160-170.
18. Tanaka T, Okamura T, Miura K, et al. A simple method to estimate population 24-h urinary sodium and potassium excretion using a casual urine specimen. J Hum Hypertens. 2002;16(2):97-103.
19. Junge W, Wilke B, Halabi A, Klein G. Determination of reference intervals for serum creatinine, creatinine excretion and creatinine clearance with an enzymatic and a modified Jaffé method. Clin Chim Acta. 2004;344(1–2):137-148.
20. Llorch K, Rakova N, Dahlmann A, et al. Agreement between 24-hour salt ingestion and sodium excretion in a controlled environment. Hypertension. 2015;66(4):850-857.
21. Lioe HN, Apriyantono A, Takara K, Wada K, Yasuda M. Umami Taste Enhancement of MSG/NaCl Mixtures by Subthreshold L-α-Aromatic Amino Acids. J Food Sci. 2005;70(7):s401-s405.
22. Halpern BP. What’s in a Name? Are MSG and Umami the Same? Chem Senses. 2002;27(9):845-846.
23. Huang L, Crino M, Wu JH, et al. Mean population salt intake estimated from 24-h urine samples and spot urine samples: a systematic review and meta-analysis. Int J Epidemiol. 2016;45(5):239-250.
24. Cogswell ME, Loria CM, Terry AL, et al. Estimated 24-Hour Urinary Sodium and Potassium Excretion in US Adults. JAMA. 2018;319(12):1209-1220.
25. Johnson C, Mohan S, Rogers K, et al. Mean Dietary Salt Intake in Urban and Rural Areas in India: A Population Survey of 1395 Persons. J Am Heart Assoc. 2017;6(1).
26. Wu JH, Halpern BP. Sodium intake as measured by urinary sodium creatinine excretion in a random and opportunistic sample in Australia. BMJ Open. 2014;4(1):e003720.
27. Mente A, Dagenais G, Wielgosz A, et al. Assessment of Dietary Sodium and Potassium in Canadians Using 24-Hour Urinary Collection. Can J Cardiol. 2016;32(3):319-326.
28. Tan M, He FJ, Wang C, MacGregor GA. Twenty-Four-Hour Urinary Sodium and Potassium Excretion in China: A Systematic Review and Meta-Analysis. J Am Heart Assoc. 2019;8(8):e012923.
29. Neupane D, Rijal A, Henry ME, et al. Mean dietary salt intake in Nepal: A population survey with 24-hour urine collections. J Clin Hypertens. 2020;22(2):273-279.
30. Zaman MM, Choudhury SR, Ahmed J, Khandaker RK, Rouf MA, Malik A. Salt Intake in an Adult Population of Bangladesh. Glob Heart. 2017;12(3):265-266.
31. Aekplakorn W, Nitityanan W, Sornpaisarn B, Kananarak P. Bureau of Non Communicable Diseases Department of Disease Control. Thai National Health Examination Survey, NHES V; 2016.
32. He FJ, Marrero NM, MacGregor GA. Salt intake is related to soft drink consumption in children and adolescents: a link to obesity? Hypertension. 2008;51(3):629-634.
33. Lee SK, Kim MK. Relationship of sodium intake with obesity among Korean children and adolescents: Korea national health and nutrition examination survey. Brit J Nutr. 2016;115(5):834-841.
34. Ma Y, He FJ, MacGregor GA. High salt intake. Hypertension. 2015;66(4):843-849.
35. Lee J, Hwang Y, Kim K-N, et al. Associations of urinary sodium levels with overweight and central obesity in a population with a sodium intake, sugar-sweetened beverage consumption, and obesity risk. Pediatrics. 2013;131(1):14-21.
36. Drenowatz C, Shook RP, Hand GA, Hébert JR, Blair SN. The independent association between diet quality and body composition. Sci Rep. 2014;4:4928.
37. Fonseca-Alañiz MH, Brito LC, Borges-Silva CN, Takada J, Andreotti S, Lima FB. High dietary sodium intake increases white adipose tissue mass and plasma leptin in rats. Obesity. 2007;15(9):2200-2208.
weight status in healthy children and adolescents. Public Health Nutr. 2012;15(3):433-441.

41. Quintiliano Scarpelli D, Pinheiro Fernandes AC, Rodriguez Osic L, Pizarro Quevedo T. Changes in nutrient declaration after the food labeling and advertising law in Chile: A longitudinal approach. Nutrients. 2020;12(8):2371.

42. Park H-K, Lee Y, Kang B-W, et al. Progress on sodium reduction in South Korea. BMJ Global Health. 2020;5(5):e002028.

43. Jackson SL, Cogswell ME, Zhao L, et al. Association between urinary sodium and potassium excretion and blood pressure among adults in the United States: National health and nutrition examination survey, 2014. Circulation. 2018;137(3):237-246.

44. Muntzel M, Drüeke T. A comprehensive review of the salt and blood pressure relationship. Am J Hypertens. 1992;5(4 Pt 1):1s-42s.

45. Balafa O, Kalaitzidis RG. Salt sensitivity and hypertension. J Hum Hypertens. 2020.

46. Health Data Center (HDC). Department of disease control Ministry of public health. 2019; https://hdcservice.moph.go.th/hdc/main/index_pk.php

47. Kieneker LM, Gansevoort RT, Mukamal KJ, et al. Urinary potassium excretion and risk of developing hypertension. Hypertension. 2014;64(4):769-776.

48. World Health O. Guideline: Sodium intake for adults and children. 2012 http://www.who.int/nutrition/publications/guidelines/sodium_intake/en/

49. Turban S, Thompson CB, Parekh RS, Appel LJ. Effects of sodium intake and diet on racial differences in urinary potassium excretion: results from the dietary approaches to stop hypertension (DASH)-Sodium trial. Am J Kidney Dis. 2013;61(1):88-95.

50. Greer RC, Marklund M, Anderson CAM, et al. Potassium-enriched salt substitutes as a means to lower blood pressure. Hypertension. 2020;75(2):266-274.

How to cite this article: Chailimpamontree W, Kantachuvesiri S, Aekplakorn W, et al. Estimated dietary sodium intake in Thailand: A nationwide population survey with 24-hour urine collections. J Clin Hypertens. 2021;23:744–754. https://doi.org/10.1111/jch.14147