

K-SALT Equation for Urinary Sodium Estimation in CKD



Semin Cho¹, Hayne Cho Park², Woo Yeong Park³, Seo Rin Kim⁴, Yong Chul Kim⁵, Han Ro⁶, Sihyung Park⁷, Chung Hee Baek⁸, Sang Heon Suh⁹, Shin Young Ahn¹⁰, Jung Nam An¹¹, Jangwook Lee¹², Chung Sik Lee¹³, Haekyung Lee¹⁴, Hyunjeong Cho¹⁵, Ji-Young Choi¹⁶, Seun Deuk Hwang¹⁷, Jin Ho Hwang¹⁸, Ji In Park¹⁹, Hyeong Cheon Park²⁰ and Ji Yong Jung²¹

¹Department of Internal Medicine, Chung-Ang University Gwangmyeong Hospital, Gyeonggi, Republic of Korea; ²Department of Internal Medicine, Kangnam Sacred Heart Hospital, Seoul, Republic of Korea; ³Department of Internal Medicine, Keimyung University School of Medicine, Keimyung University Dongsan Hospital, Daegu, Republic of Korea; ⁴Department of Internal Medicine, Pusan National University School of Medicine, Yangsan, Republic of Korea; ⁵Department of Internal Medicine, Seoul National University Hospital, Seoul, Republic of Korea; ⁶Department of Internal Medicine, Truewords Dialysis Clinic, Incheon, Republic of Korea; ⁷Department of Internal Medicine, Haeundae Paik Hospital, Busan, Republic of Korea; ⁸Department of Internal Medicine, Asan Medical Center, Seoul, Republic of Korea; ⁹Department of Internal Medicine, Chonnam National University Medical School, Gwangju, Republic of Korea; ¹⁰Department of Internal Medicine, Seoul National University Bundang Hospital, Seongnam, Republic of Korea; ¹¹Department of Internal Medicine, Hallym University Sacred Heart Hospital, Anyang, Republic of Korea; ¹²Department of Internal Medicine, Dongguk University Ilsan Hospital, Gyeonggi, Republic of Korea; ¹³Department of Internal Medicine, Cheju Halla General Hospital, Jeju, Republic of Korea; ¹⁴Department of Internal Medicine, Soonchunhyang University Seoul Hospital, Seoul, Republic of Korea; ¹⁵Department of Internal Medicine, Chungbuk National University Hospital, Chungbuk National University College of Medicine, Cheongju, Republic of Korea; ¹⁶Department of Internal Medicine, School of Medicine, Kyungpook National University, Daegu, Republic of Korea; ¹⁷Department of Internal Medicine, Inha University Hospital, Incheon, Republic of Korea; ¹⁸Department of Internal Medicine, Chung-Ang University Hospital, Seoul, Republic of Korea; ¹⁹Department of Internal Medicine, Kangwon National University Hospital, Kangwon National University School of Medicine, Chuncheon, Republic of Korea; ²⁰Department of Internal Medicine, Gangnam Severance Hospital and Severance Institute for Vascular and Metabolic Research, Yonsei University College of Medicine, Seoul, Republic of Korea; and ²¹Department of Internal Medicine, Gachon University Gil Medical Center, Gachon University College of Medicine, Incheon, Republic of Korea

Introduction: Accurate estimation of 24-hour urinary sodium (24 hUNa) excretion is essential for assessing sodium intake and guiding salt restriction in patients with chronic kidney disease (CKD). However, existing equations have shown limited validity in Korean populations. Therefore, we aimed to develop and validate the Korean sodium assessment tool (K-SALT), an equation for estimating 24 hUNa excretion from spot urine specifically designed for Korean patients with CKD.

Methods: This study employed a hybrid cohort design across 16 teaching hospitals in Korea. Data for the development and internal validation cohorts were prospectively collected according to a standardized urine collection protocol, whereas data for the external validation cohort were retrospectively obtained from an independent patient group. Multiple regression models were constructed using demographic, anthropometric, and spot urine variables, and their performance was compared with existing equations using intraclass correlation coefficients (ICC), mean bias, and area under the curve (AUC) analyses.

Results: A total of 1637 patients with CKD were included in this study (1077 for the development and internal validation, and 560 for the external validation). The K-SALT equation demonstrated superior performance compared with previously reported formulas, showing higher ICC and AUC values with smaller mean prediction error. External validation confirmed its robustness across CKD stages and subgroups.

Conclusion: The K-SALT study provides the first large-scale, population-specific equation for estimating 24hUNa excretion in Korean patients with CKD. By better reflecting the demographic and clinical

characteristics of this population, the K-SALT equation enables more accurate assessment of sodium intake and supports individualized dietary sodium management in CKD care.

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KEYWORDS: 24-hour urine sodium; chronic kidney disease; spot urine sodium; salt intake

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Excess dietary sodium intake is a well-recognized risk factor for hypertension, cardiovascular disease, and CKD progression. In patients with CKD, sodium restriction is a cornerstone of nonpharmacologic management, as it helps to mitigate fluid overload, improve blood pressure control, and slow the decline of kidney function.¹⁻³ International guidelines, including those from Kidney Disease: Improving Global Outcomes (KDIGO), recommend limiting sodium intake to less than 2 g/day (approximately 5 g/day of salt) in CKD populations.⁴ Nevertheless, adherence to a low-sodium diet remains challenging in clinical practice because of cultural, behavioral, and dietary factors.

Traditionally, 24 hUNa excretion is considered the gold standard for estimating daily sodium intake, under the assumption that sodium balance is relatively stable and urinary sodium closely reflects dietary intake. However, complete 24-hour urine collection is labor-intensive, inconvenient, and prone to collection errors, which limits its practicality in both clinical and epidemiologic studies. To overcome these limitations, several predictive equations based on spot urine measurements, such as those proposed by Kawasaki, Tanaka, INTERSALT, and Nerbass, have been developed to estimate 24 hUNa excretion.⁵⁻⁸

Although these equations provide practical alternatives, their accuracy and generalizability are limited. Notably, none of the existing models were developed or validated in Korean patients with CKD, whose demographic, dietary, and clinical characteristics differ substantially from those of the original derivation cohorts. For instance, traditional Korean diets include a high intake of salted and fermented foods such as kimchi and soy-based sauces, which may generate unique patterns of sodium intake and excretion.^{9,10} Furthermore, CKD alters kidney handling of sodium, potassium, and creatinine, potentially diminishing the predictive accuracy of equations derived from healthy populations when applied to patients with reduced kidney function.^{11,12}

Therefore, we conducted the K-SALT study to develop and validate a population-specific equation for estimating 24hUNa excretion using spot urine samples from Korean patients with CKD. This study aimed to improve the precision of sodium intake assessment and provide a reliable, clinically applicable tool to enhance

individualized dietary counseling and optimize CKD management.

METHODS

Study Design and Setting

The K-SALT study was a multicenter hybrid cohort study conducted across 16 tertiary teaching hospitals in South Korea. This study was designed to develop and validate a predictive equation for estimating 24 hUNa excretion from spot urine measurements in patients with CKD. A hybrid design combining prospectively collected and retrospectively obtained data was used to enhance generalizability and enable both internal and external validation. Detailed information on data collection procedures is described in the following section.

Study Population

The development and internal validation cohorts consisted of adult outpatients with CKD who were regularly followed in nephrology clinics. In this study, CKD was defined according to the Kidney Disease: Improving Global Outcomes criteria as either an estimated glomerular filtration rate (eGFR) < 60 ml/min per 1.73 m² or evidence of kidney damage, such as persistent albuminuria or proteinuria, for at least 3 months. Data were prospectively collected between June 2024 and September 2025 according to a pre-defined standardized urine collection protocol established by the K-SALT research committee.

Participants were instructed to begin 24-hour urine collection 1 day before their scheduled outpatient visit. The first voided urine at the start of the collection period was discarded, and all subsequent urine was collected, including the final void at the end of the 24-hour period. Spot urine samples were obtained during the same clinic visit when the 24-hour urine collection was submitted. The samples were collected as random spot urine without restriction to a specific time of day. During the urine collection period, participants were instructed to maintain their usual diet without any dietary restrictions or modifications, to ensure that the collected samples reflected their habitual sodium intake. For 24 hUNa, urine collections with a total volume < 500 ml were excluded to ensure the completeness of 24-hour urine collection. Samples with a 24 hUNa ≥ 500 mEq/day were excluded, as such values were unlikely

to reflect habitual sodium intake and were considered to be influenced by transient, nonphysiological factors, including acute fluid or sodium administration. Participants whose data were collected during this period were randomly assigned to either the development or internal validation cohort, according to their institutional identification numbers (even-numbered cases: development; odd-numbered cases: validation).

For the external validation cohort, data were retrospectively extracted from electronic medical records of adult patients with CKD (aged ≥ 18 years) who underwent both 24-hour urine collection and spot urine testing within 7 days during nephrology outpatient visits or hospitalization between January 1, 2013, and May 31, 2025. Patients were excluded if urine collection was performed during treatment for acute kidney injury—defined according to the Kidney Disease: Improving Global Outcomes criteria as an increase in serum creatinine of ≥ 0.3 mg/dl within 48 hours or ≥ 1.5 times the baseline value— or while receiving kidney replacement therapy (hemodialysis, peritoneal dialysis, or kidney transplantation). This retrospective cohort was entirely independent of the prospectively collected dataset and was used solely for external validation of the developed model.

The study complied with the principles of the Declaration of Helsinki. The study protocol was reviewed and approved by the institutional review boards of all participating hospitals as follows: Gachon University Gil Medical Center (GBIRB2025-114), Hallym University Kangnam Sacred Heart Hospital (HKS 2025-06-012), Kangwon National University Hospital (KNUH-2025-08-004), Keimyung University Dongsan Hospital (2025-12-041), Dongguk University Ilsan Hospital (DUIH-2025-10-008), Soonchunhyang University Seoul Hospital (2025-09-014), Pusan National University Yangsan Hospital (11-2025-064), Inha University Hospital (2025-11-038), Chonnam National University Hospital (CNUH-2025-329), Cheju Halla General Hospital (2025-L15), Chung-Ang University Gwangmyeong Hospital (E-2507-253-100), Chungbuk National University Hospital (2025-11-005), Kyungpook National University Chilgok Hospital (KNUCH IRB 2025-08-007), Hallym University Sacred Heart Hospital (HALLYM 2025-05-005-001), and Inje University Haeundae Paik Hospital (HPIRB 2025-11-033). Because all data were collected according to a pre-established protocol and analyzed retrospectively, the requirement for informed consent was waived.

Data Collection

Demographic and clinical characteristics were collected, including age, sex, residential area, body mass index (BMI), blood pressure, smoking status, alcohol

consumption, presence of hypertension or diabetes, and the underlying cause of CKD. Laboratory measurements comprised 24-hour urine sodium, potassium, creatinine, and protein, and total urine volume, as well as spot urine sodium, potassium, creatinine, and protein concentrations on the same day. Serum creatinine was measured, and the eGFR was calculated using the Chronic Kidney Disease Epidemiology Collaboration 2021 equation.¹³ In addition, information on medication use, including loop diuretics, thiazide diuretics, mineralocorticoid receptor antagonists, and sodium–glucose cotransporter-2 inhibitors, was obtained from medical records and patient interviews conducted at the time of urine collection. Although participants were not required to modify their prescribed medication regimens to reflect real-world clinical conditions, all documented medication data were analyzed to account for their potential influence on urinary sodium handling.

Development of the Predictive Equation

A prediction model for estimating 24hUNa excretion was developed using a multiple linear regression framework. Model development and analysis were performed using R software (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria).

Candidate predictors were selected *a priori* based on clinical applicability, physiological relevance to sodium handling, and availability in routine nephrology practice. The following variables were included as independent predictors: spot urine sodium, potassium, and creatinine concentrations; serum creatinine; age; sex; height; and weight.

Because several variables exhibited right-skewed distributions, log-transformation was applied to both dependent and independent variables to stabilize variance and satisfy regression assumptions. The model coefficients were first estimated using a log–log regression, and the logarithmic terms were then back-transformed to derive a multiplicative exponential equation expressed as the product of power terms. This transformation reduced the influence of data skewness and enabled a multiplicative model structure that ensured mathematical consistency and physiological interpretability across the predictor range. Sex-specific models were developed to account for known physiological differences in sodium excretion between males and females.

External Validation Cohort

The external validation dataset was independent of the development and internal validation cohorts, comprising adult patients with CKD retrospectively identified according to the criteria described in the Study Population section.

All relevant clinical and laboratory variables, including age, sex, BMI, presence of hypertension or diabetes, serum creatinine, eGFR, and urinary electrolyte parameters, were collected using the same definitions and measurement procedures as those applied in the K-SALT cohort.

This external cohort was used exclusively to assess the generalizability and predictive performance of the newly developed K-SALT equation in an independent patient population.

Validation of Developed Equation

The K-SALT equation and previously established prediction equations (Kawasaki, Tanaka, INTERSALT, and Nerbass equations) were applied to both the internal and external cohort, and their predictive performances were compared. This dual-cohort validation strategy was employed to rigorously test the generalizability and reliability of the K-SALT equation across different patient populations, comparing its consistency with existing equations.

Statistical Analyses

Continuous variables were summarized as means $\pm$ SDs for normally distributed data and as medians with interquartile ranges for non-normally distributed data, whereas categorical variables were expressed as counts and percentages. Group comparisons were performed using the independent *t* test or analysis of variance for normally distributed continuous variables and the Kruskal–Wallis test for non-normally distributed variables. Categorical variables were compared using the chi-square test or Fisher exact test, as appropriate.

For model construction, multiple linear regression was used to develop the predictive equation, and adjusted R^2 , residual plots, and variance inflation

factors were examined to assess model fit and multicollinearity. Model performance was evaluated by examining the coefficient of determination (R^2) and root mean square error between predicted and measured 24 hUNa measurements. Agreement between predicted and observed sodium excretion was further assessed using Bland–Altman plots, Pearson correlation coefficients, intraclass correlation coefficients (ICC), and Lin's concordance correlation coefficients.

To evaluate discriminative ability, receiver operating characteristic (ROC) curve analyses were performed to assess each equation's accuracy in identifying individuals with high sodium excretion, defined as 24 hUNa ≥ 150 mEq/day. The AUC for the ROC curve was calculated to compare the overall discriminative performance among models.

All statistical tests were 2-sided, and *P* values < 0.05 were considered statistically significant.

RESULTS

Baseline Characteristics

Development and Internal Validation Cohort

A total of 1077 patients with CKD were included in the analysis, with 537 assigned to the development cohort and 540 to the internal validation cohort (Figure 1). The mean age of participants was 59.3 ± 15.2 years, and 63.0% were male. The mean BMI was 25.4 ± 4.3 kg/m², 63.7% had hypertension, and 35.6% had diabetes mellitus. Baseline eGFR was 63.2 ± 29.5 ml/min per 1.73 m², with 33.5% of participants classified as CKD G3 and 13.0% as CKD G4 to G5. Baseline demographic and clinical characteristics were generally comparable between the development and validation groups, except for minor differences in BMI, serum creatinine, eGFR, and CKD stage distribution (Table 1).

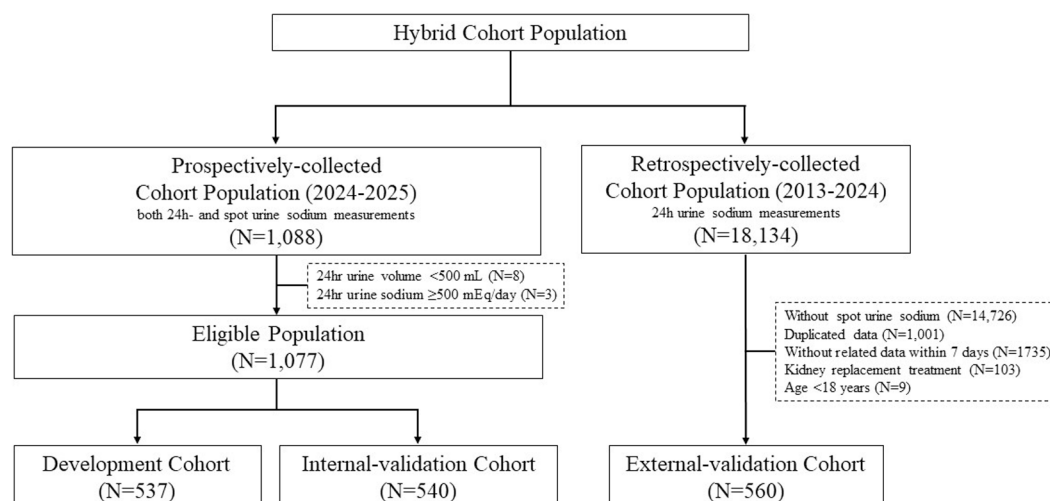


Figure 1. Flow chart.

Table 1. Baseline characteristics of study participants

Characteristics	Total (N = 1077)	Development group (n = 537)	Validation group (n = 540)	P-value
Age	59.3 ± 15.2	59.6 ± 15.4	59.0 ± 14.9	0.56
Male	679 (63.0%)	343 (63.9%)	336 (62.2%)	0.62
BMI (kg/m ²)	25.4 ± 4.3	25.6 ± 4.3	25.1 ± 4.2	0.08
Residence				0.96
Seoul/Gyeong-gi	685 (63.6%)	341 (63.5%)	344 (63.7%)	
Gangwon	24 (2.2%)	12 (2.0%)	12 (2.2%)	
Chungcheong	32 (3.0%)	18 (3.4%)	14 (2.6%)	
Yeongnam	280 (26.0%)	138 (25.7%)	142 (26.3%)	
Honam	44 (4.1%)	21 (3.9%)	23 (4.3%)	
Jeju	12 (1.1%)	7 (1.3%)	5 (0.9%)	
Smoking				0.35
Nonsmoker	627 (58.2%)	308 (57.4%)	319 (59.1%)	
Ex-smoker	283 (26.3%)	136 (25.3%)	147 (27.2%)	
Current smoker	160 (14.9%)	90 (16.8%)	70 (13.0%)	
Alcohol				0.67
No	724 (67.2%)	356 (66.3%)	368 (68.1%)	
Yes	337 (31.3%)	174 (32.4%)	163 (30.2%)	
SBP	129.0 ± 16.5	129.8 ± 16.9	128.2 ± 15.9	0.12
DBP	72.3 ± 12.7	73.1 ± 12.8	71.6 ± 12.6	0.06
HTN	686 (63.7%)	358 (66.7%)	328 (60.7%)	0.05
DM	383 (35.6%)	201 (37.4%)	182 (33.7%)	0.23
Admission status				0.76
Outpatient	991 (92.0%)	496 (92.4%)	495 (91.7%)	
Inpatient	86 (8.0%)	41 (7.6%)	45 (8.3%)	
Serum Cr (mg/dl)	1.5 ± 1.0	1.6 ± 1.0	1.4 ± 1.0	0.09
eGFR (ml/min per 1.73m ²)	63.2 ± 29.5	61.6 ± 29.8	64.8 ± 29.1	0.07
CKD stage				0.09
Stage I	305 (28.3%)	146 (27.2%)	159 (29.4%)	
Stage II	271 (25.2%)	125 (23.3%)	146 (27.0%)	
Stage III	361 (33.5%)	186 (34.6%)	175 (32.4%)	
Stage IV	107 (9.9%)	57 (10.6%)	50 (9.3%)	
Stage V	33 (3.1%)	23 (4.3%)	10 (1.9%)	
Diuretics				
Loop diuretics	57 (5.3%)	26 (4.8%)	31 (5.7%)	0.60
Thiazide	27 (2.5%)	15 (2.8%)	12 (2.2%)	0.69
MR antagonist	33 (3.1%)	13 (2.4%)	20 (3.7%)	0.30
SGLT2 inhibitor	154 (14.3%)	81 (15.1%)	73 (13.5%)	0.52

BMI, body mass index; CKD, chronic kidney disease; Cr, creatinine; DBP, diastolic blood pressure; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; HTN, hypertension; MR, mineralocorticoid receptor; SBP, systolic blood pressure; SGLT2 inhibitor, sodium-glucose cotransporter 2 inhibitor.
Data are presented as the mean ± SD, or n (%).

As shown in Table 2, urinary parameters were also similar between the 2 cohorts. The mean measured 24 hUNa was 149.3 ± 73.7 mEq/day, and the mean spot

urine sodium concentration was 87.1 ± 43.1 mEq/l. Mean 24-hour urine protein was 1076.7 ± 1974.5 mg/day, and mean urine volume was approximately 1780.3 ml/day.

Table 2. Urinary parameters of study participants

Characteristics	Total (N = 1077)	Development group (n = 537)	Validation group (n = 540)	P-value
24-h urine sodium (mEq/d)	149.3 ± 73.7	153.2 ± 75.0	145.5 ± 72.3	0.09
24-h urine potassium (mEq/d)	47.4 ± 22.0	47.2 ± 21.8	47.6 ± 22.2	0.76
24-h urine creatinine (mg/d)	1078.4 ± 509.3	1061.4 ± 461.1	1095.4 ± 553.1	0.27
24-h urine creatinine (mg/dl)	67.0 ± 37.5	65.8 ± 33.6	68.3 ± 41.0	0.28
24-h urine protein (mg/d)	1076.7 ± 1974.5	1154.9 ± 2178.1	998.5 ± 1745.9	0.19
24-h urine volume (ml)	1780.3 ± 726.3	1782.1 ± 744.6	1778.5 ± 708.4	0.94
Spot urine sodium (mEq/dl)	87.1 ± 43.1	88.0 ± 43.0	86.2 ± 43.2	0.49
Spot urine potassium (mEq/dl)	45.8 ± 26.0	45.2 ± 25.2	46.4 ± 26.7	0.45
Spot urine creatinine (mg/dl)	104.4 ± 67.2	103.3 ± 62.9	105.5 ± 71.4	0.58
Spot urine protein (mg/dl)	124.2 ± 314.6	120.7 ± 201.0	127.8 ± 397.6	0.72
Creatinine clearance (ml/min)	63.0 ± 39.8	60.2 ± 37.4	65.8 ± 41.8	0.02

Data are presented as the mean ± SD.

A statistically significant positive linear relationship was observed between spot and 24 hUNa excretion ($r = 0.40$, $P < 0.001$), as shown in Figure 2.

External Validation Cohort

A total of 560 patients with CKD were included in external validation cohort (Figure 1). The mean age of participants was 57.2 ± 16.7 years, and 55.2% were male. The mean BMI was 24.4 ± 4.7 kg/m², 63.0% had hypertension, and 37.9% had diabetes mellitus. The mean eGFR was 66.0 ± 39.7 ml/min per 1.73 m², with 29.0% of participants classified as CKD G3 and 21.3% as CKD G4-G5. The mean measured 24hUNa was 146.9 ± 103.7 mEq/day, and the mean spot urine sodium concentration was 81.2 ± 46.6 mEq/l (Supplementary Table 1).

Novel Equation for Estimating 24 hUNa Excretion

Using the development cohort, a multivariable linear regression model was constructed to predict 24hUNa.

The independent variables included spot urine sodium, potassium, and creatinine, and serum creatinine; age; sex; height; and weight. Because of known sex-related physiological differences in sodium handling, separate equations were developed for male and female (Table 3).

The resulting predictive equation was designated as the K-SALT equation, reflecting its derivation from a representative Korean CKD population and its purpose to estimate daily sodium excretion from routinely available clinical and laboratory variables.

Validation of the K-SALT Equation

Agreement Between Measured and Estimated Sodium Excretion Based on Mean Difference Analysis

The agreement between measured and estimated 24 hUNa excretion was evaluated by quantifying the mean difference and its 95% limits of agreement (LOA). In the internal validation cohort, the K-SALT equation demonstrated a mean bias of 5.68, with 95% LOA ranging from 113.33 to 124.70. In comparison, both the Kawasaki and INTERSALT equations exhibited larger absolute mean bias and wider 95% LOA ranges. Furthermore, whereas the Tanaka equation showed a smaller absolute mean bias (-2.23) but a wider 95% LOA range (-138.21 to 133.76), the Nerbass equation presented a slightly narrower 95% LOA range (-73.01 to 164.23) but a substantially larger mean bias (45.61). Overall, the K-SALT equation demonstrated the closest agreement with measured 24 hUNa values among all evaluated models. Across subgroups defined by sex,

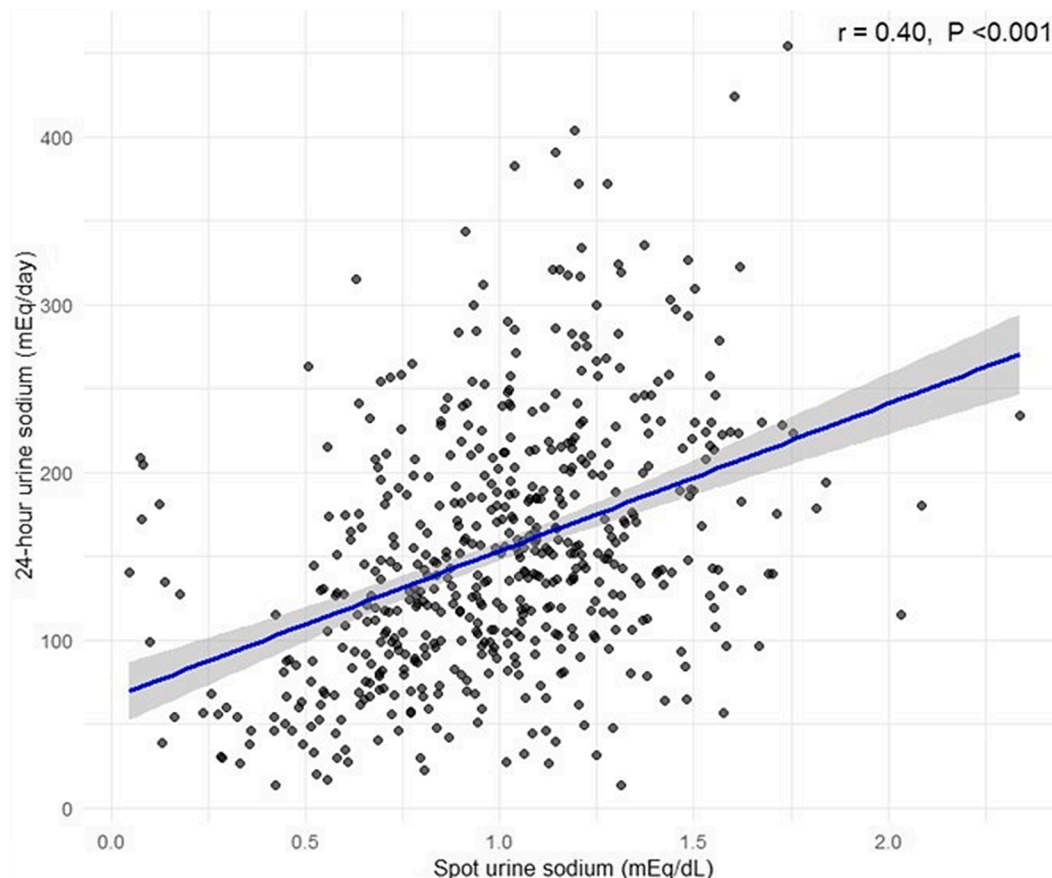


Figure 2. Scatter plot showing the correlation between 24-hour and spot urine sodium excretion.

Table 3. Developed equation for estimating 24-hour urinary sodium excretion

Male	$24 \text{ h urine Na} = 0.021497 \times \text{age}^{0.085} \times \text{height}^{0.863} \times \text{weight}^{0.829} \times \text{spot urine Na}^{0.225} \times \text{spot urine K}^{0.043} \times \text{spot urine Cr}^{0.129} \times \text{serum Cr}^{0.107}$
Female	$24 \text{ h urine Na} = 0.001316 \times \text{age}^{-0.277} \times \text{height}^{1.878} \times \text{weight}^{0.436} \times \text{spot urine Na}^{0.485} \times \text{spot urine K}^{0.199} \times \text{spot urine Cr}^{0.380} \times \text{serum Cr}^{0.097}$

age, BMI, eGFR, proteinuria, and sodium excretion level, the mean difference of the novel equation remained within comparable limits, indicating stable measurement agreement across strata (Figure 3, Table 4).

In the external validation cohort, similar patterns were observed (Figure 4, Table 5). The K-SALT equation showed a small overall bias (13.70 mEq/day; 95% LOA -171.63 to 199.03 mEq/day), maintaining consistent accuracy across subgroups. Although, the Tanaka equation exhibited the smallest mean bias in absolute value (-12.24 mEq/day), its 95% LOA were wider than those of the K-SALT. The Kawasaki equation showed a larger mean bias (-63.60 mEq/day), whereas the INTERSALT and Nerbass equations had ranges of 95% LOA (-173.94 to 208.28 mEq/day and -134.86 to 249.40 mEq/day, respectively) comparable to that of K-SALT, but with greater mean biases (17.17 mEq/day and 57.27 mEq/day, respectively). Among subgroups defined by kidney function, the K-SALT equation maintained good agreement even in participants with eGFR < 60 ml/min per 1.73 m², showing a smaller bias than other equations.

Correlation Between Measure and Estimated Sodium Excretion

The linear relationship between measured and estimated 24 hUNa excretion was analyzed using the Pearson product-moment correlation coefficient.

In the internal validation cohort (Table 6), the K-SALT equation demonstrated a moderate positive correlation with measured sodium excretion ($r = 0.52$; 95% confidence interval [CI]: 0.45–0.57; $P < 0.001$) comparable to the Nerbass equation ($r = 0.51$; 95% CI: 0.45–0.57; $P < 0.001$) and higher than the Kawasaki ($r = 0.36$; 95% CI: 0.29–0.44; $P < 0.001$), Tanaka ($r = 0.37$; 95% CI: 0.29–0.44; $P < 0.001$), and INTERSALT equations ($r = 0.42$; 95% CI: 0.35–0.49; $P < 0.001$). Across subgroups defined by sex, age, BMI, proteinuria, and eGFR, the K-SALT equation consistently maintained moderate correlations. Notably, the similar correlation patterns were observed across subgroups ($r = 0.43$ for CKD G2, $r = 0.52$ for CKD G3, and $r = 0.54$ for CKD G4–G5; all $P < 0.001$). The association remained significant even in participants with heavy proteinuria ($r = 0.43$; $P < 0.001$ for 24-hour urine protein ≥ 1000 mg/day).

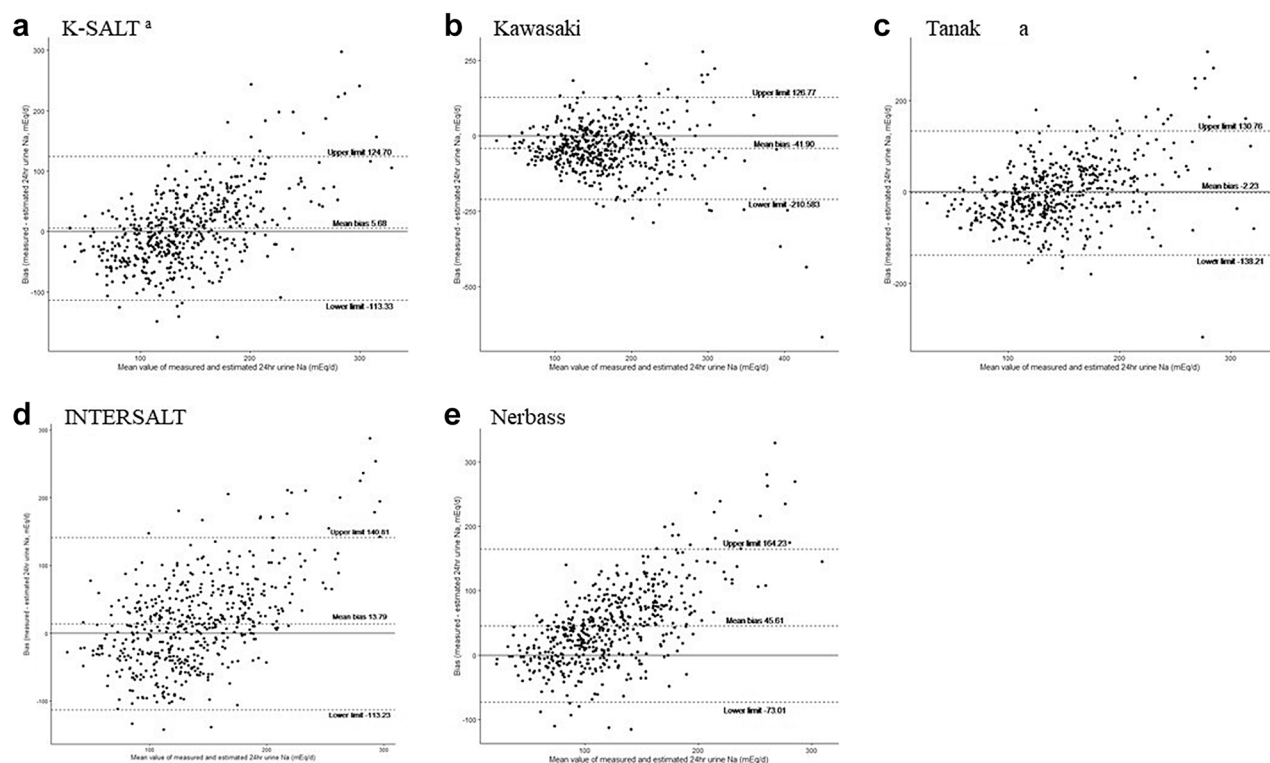


Figure 3. Bland-Altman plots of measured 24-hour urine Na excretion and estimated 24-hour urine Na excretion by (a) K-SALT, (b) Kawasaki, (c) Tanaka, (d) INTERSALT, and (e) Nerbass equation (internal validation). ^a Indicates that the predictive performance is significantly better than that of the other equations.

Table 4. Bland–Altman statistics for bias between measured and estimated 24-h urinary sodium excretion (internal validation)

Variables	K–SALT	Kawasaki	Tanaka	INTERSALT	Nerbass
Mean bias (lower limit of agreement, upper limit of agreement)					
All	5.68 (-113.33 to 124.70) ^a	-41.90 (-210.58 to 126.77)	-2.23 (-138.21 to 133.76)	13.79 (-113.23 to 140.81)	45.61 (-73.01 to 164.23)
Sex					
Male	3.70 (-121.37 to 128.76)	-41.06 (-227.58 to 145.47)	5.23 (-141.61 to 152.07)	3.41 (-129.79 to 136.60)	46.71 (-78.68 to 172.10)
Female	8.97 (-99.31 to 117.25)	-43.29 (-177.76 to 91.18)	-14.56 (-126.62 to 97.50)	30.96 (-77.33 to 139.26)	43.80 (-62.91 to 150.51)
Age					
≥ 65	7.51 (-102.19 to 117.21)	-43.69 (-195.33 to 107.95)	-9.64 (-135.20 to 115.92)	12.37 (-112.11 to 136.85)	46.83 (-63.65 to 157.31)
< 65	4.42 (-120.77 to 129.60)	-40.66 (-220.41 to 139.09)	2.91 (-139.18 to 145.01)	14.78 (-114.14 to 143.70)	44.77 (-79.34 to 168.87)
BMI (kg/m ²)					
≥ 25	13.03 (-123.82 to 149.89)	-30.70 (-213.65 to 152.25)	14.04 (-138.15 to 166.23)	24.36 (-117.69 to 166.41)	49.45 (-88.27 to 187.17)
18.5 ≤ < 25	-0.19 (-100.20 to 99.82)	-52.19 (-206.50 to 102.12)	-16.16 (-128.52 to 96.20)	4.68 (-104.82 to 114.18)	42.47 (-56.78 to 141.72)
< 18.5	-11.71 (-81.54 to 58.13)	-54.08 (-176.58 to 68.41)	-30.76 (-126.87 to 65.34)	-4.04 (-93.80 to 85.72)	37.37 (-35.89 to 110.64)
eGFR (ml/min per 1.73 m ²)					
≥ 90	9.52 (-126.58 to 145.61)	-42.03 (-225.90 to 141.85)	5.39 (-145.57 to 156.34)	28.81 (-109.59 to 167.22)	53.27 (-79.73 to 186.27)
60 ≤ < 90	0.62 (-122.28 to 123.51)	-42.50 (-209.81 to 124.82)	-1.78 (-139.59 to 136.02)	13.41 (-108.42 to 135.23)	42.55 (-80.19 to 165.29)
30 ≤ < 60	6.43 (-98.47 to 111.33)	-34.55 (-175.04 to 105.95)	-1.38 (-121.44 to 118.68)	9.36 (-108.23 to 126.95)	44.42 (-59.71 to 148.56)
< 30	8.64 (-106.58 to 123.86)	-63.54 (-277.32 to 150.24)	-21.58 (-164.90 to 121.74)	-1.64 (-138.10 to 134.82)	41.79 (-78.77 to 162.34)
24–h urine protein (mg/d)					
≥ 1000	18.18 (-111.90 to 148.25)	-36.84 (-215.84 to 142.16)	9.27 (-133.51 to 152.06)	18.92 (-110.90 to 148.73)	58.63 (-63.96 to 181.21)
500 ≤ < 1000	6.16 (-106.70 to 119.01)	-44.04 (-187.34 to 99.26)	-4.77 (-125.37 to 115.82)	12.08 (-114.76 to 138.93)	44.39 (-67.47 to 156.25)
< 500	0.70 (-114.45 to 115.84)	-41.26 (-197.95 to 115.44)	-4.97 (-137.21 to 127.27)	12.63 (-113.46 to 138.72)	40.91 (-76.96 to 158.78)
24–h urine sodium (mEq/d)					
≥ 150	51.16 (-58.88 to 161.20)	-4.57 (-187.37 to 178.24)	46.65 (-84.37 to 177.67)	61.80 (-50.41 to 174.01)	93.60 (-12.01 to 199.22)
100 ≤ < 150	-11.63 (-76.92 to 53.67)	-59.10 (-209.87 to 91.68)	-22.39 (-111.77 to 66.99)	-2.66 (-81.26 to 75.93)	27.95 (-30.61 to 86.50)
< 100	-44.61 (-115.91 to 26.70)	-79.93 (-191.61 to 31.74)	-54.58 (-131.11 to 21.94)	-41.28 (-119.96 to 37.41)	-8.11 (-73.62 to 57.40)

BMI, body mass index; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool.

^aIndicates that the predictive performance is significantly better than that of the other equations.

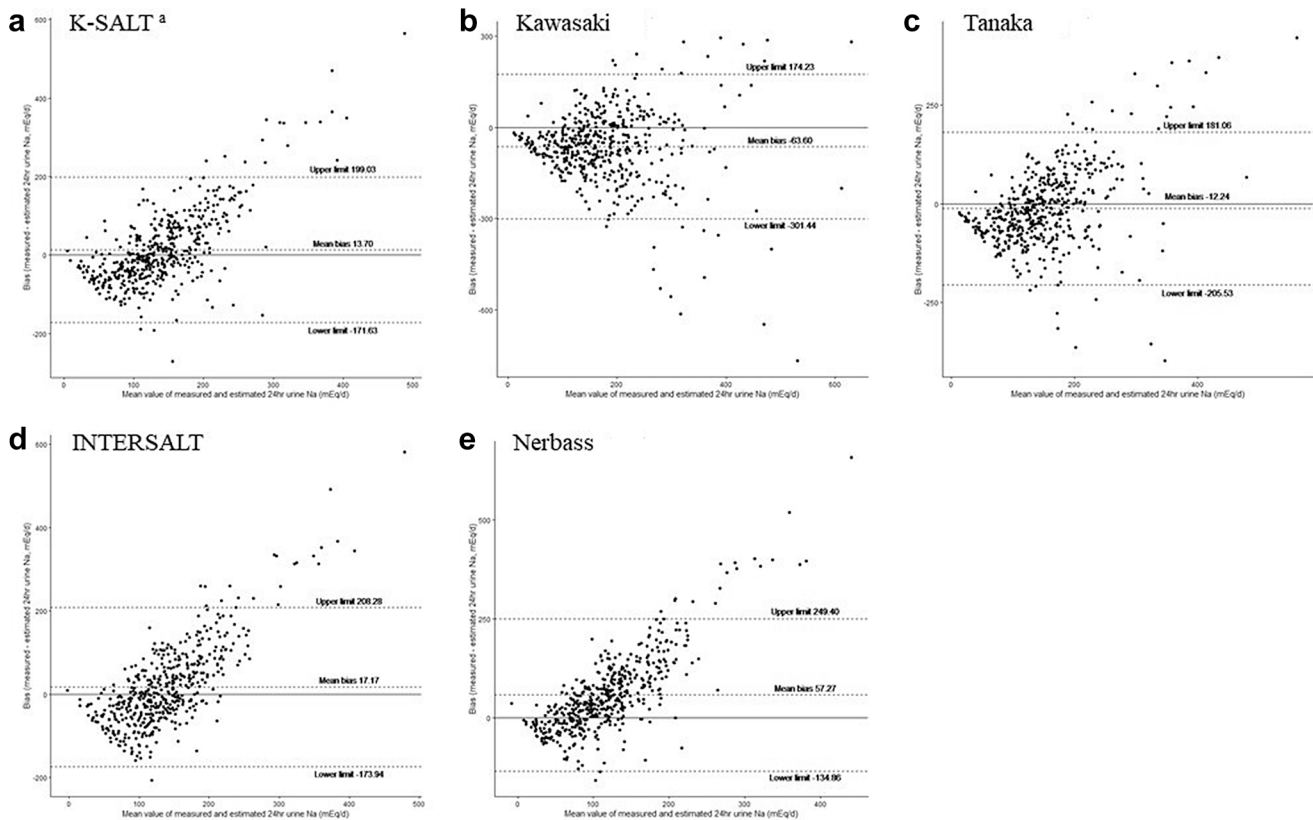


Figure 4. Bland–Altman plots of measured 24-hour urine Na excretion and estimated 24-hour urine Na excretion by (a) K-SALT, (b) Kawasaki, (c) Tanaka, (d) INTERSALT, and (e) Nerbass equation (external validation). ^aIndicates that the predictive performance is significantly better than that of the other equations.

Table 5. Bland–Altman statistics for bias between measured and estimated 24-h urinary sodium excretion (external validation)

Variables	K–SALT	Kawasaki	Tanaka	INTERSALT	Nerbass
Mean bias (lower limit of agreement, upper limit of agreement)					
All	13.70 (-171.63 to 199.03) ^a	-63.60 (-301.44 to 174.23)	-12.24 (-205.53 to 181.06)	17.17 (-173.94 to 208.28)	57.27 (-134.86 to 249.40)
Sex					
Male	14.34 (-181.35 to 210.02)	-57.98 (-299.60 to 183.64)	-0.70 (-200.14 to 198.74)	4.04 (-198.69 to 206.77)	56.95 (-149.12 to 263.03)
Female	12.87 (-158.60 to 184.35)	-70.87 (-303.52 to 161.79)	-27.05 (-208.54 to 154.43)	34.14 (-135.60 to 203.87)	57.68 (-115.26 to 230.61)
Age					
≥ 65	13.41 (-167.91 to 194.73)	-76.40 (-315.22 to 162.42)	-26.36 (-215.68 to 162.96)	23.69 (-166.93 to 214.32)	61.69 (-130.00 to 253.38)
< 65	13.86 (-173.91 to 201.62)	-56.63 (-293.19 to 179.93)	-4.44 (-198.51 to 189.63)	13.62 (-177.71 to 204.94)	54.86 (-137.65 to 247.37)
BMI (kg/m ²)					
≥ 25	11.99 (-170.74 to 194.71)	-54.10 (-303.80 to 195.60)	-4.70 (-207.24 to 197.85)	16.19 (-176.61 to 208.98)	47.09 (-145.54 to 239.71)
18.5 ≤ < 25	10.95 (-166.89 to 188.79)	-72.53 (-301.63 to 156.57)	-19.53 (-200.44 to 161.38)	13.91 (-165.60 to 193.41)	59.13 (-119.37 to 237.63)
< 18.5	37.93 (-195.04 to 270.91)	-59.51 (-284.07 to 165.05)	-7.95 (-221.66 to 205.75)	40.78 (-199.63 to 281.18)	97.01 (-145.91 to 339.94)
eGFR (ml/min per 1.73 m ²)					
≥ 90	32.42 (-197.24 to 262.08)	-59.59 (-361.73 to 242.54)	2.77 (-234.21 to 239.75)	38.81 (-193.33 to 270.94)	78.29 (-160.96 to 317.54)
60 ≤ < 90	24.62 (-131.57 to 180.81)	-48.21 (-260.50 to 164.09)	5.11 (-156.94 to 167.15)	36.74 (-125.14 to 198.62)	73.01 (-85.67 to 231.69)
30 ≤ < 60	8.28 (-154.23 to 170.80)	-56.44 (-273.19 to 160.30)	-12.46 (-190.22 to 165.30)	8.74 (-156.71 to 174.18)	49.79 (-112.20 to 211.78)
< 30	-13.87 (-169.88 to 142.15)	-92.25 (-263.98 to 79.49)	-47.34 (-201.50 to 106.82)	-17.70 (-180.46 to 145.06)	25.24 (-140.78 to 191.26)
24-hour urine sodium (mEq/d)					
≥ 150	85.33 (-102.00 to 272.65)	-6.28 (-235.88 to 223.31)	56.92 (-129.60 to 243.45)	95.34 (-87.38 to 278.07)	135.85 (-51.57 to 323.28)
100 ≤ < 150	-8.40 (-82.49 to 65.69)	-89.22 (-317.13 to 138.69)	-37.26 (-168.69 to 94.17)	-7.08 (-81.13 to 66.97)	32.89 (-31.60 to 97.39)
< 100	-58.64 (-142.01 to 24.73)	-116.40 (-309.06 to 76.26)	-79.70 (-191.09 to 31.69)	-61.69 (-143.00 to 19.62)	-22.02 (-98.75 to 54.72)

BMI, body mass index; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool.

^aIndicates that the predictive performance is significantly better than that of the other equations.

In the external validation cohort (Table 7), the K-SALT equation demonstrated a moderate positive correlation with measured sodium excretion ($r = 0.43$; 95% CI: 0.35–0.50; $P < 0.001$), comparable to the Tanaka equation ($r = 0.41$; 95% CI: 0.33–0.48; $P < 0.001$) and stronger than the Kawasaki ($r = 0.38$; 95% CI: 0.30–0.45; $P < 0.001$), INTERSALT ($r = 0.36$; 95% CI: 0.28–0.44; $P < 0.001$), and Nerbass equations ($r = 0.35$; 95% CI: 0.27–0.42; $P < 0.001$). Subgroup analyses confirmed that the correlation for the K-SALT equation was consistent across sex, age, BMI, or kidney function strata. In particular, correlation strength increased in older participants ($r = 0.50$; 95% CI: 0.37–0.60 for age ≥ 65 years) and remained stable across eGFR strata ($r = 0.44$ for CKD G1, $r = 0.44$ for CKD G2, $r = 0.34$ for CKD G3, and $r = 0.41$ for CKD G4–G5; all $P < 0.001$).

To evaluate both precision and accuracy, agreement was further assessed using Lin's concordance correlation coefficients. Overall, concordance correlation coefficients values were lower than Pearson correlation coefficients. In the internal validation cohort, the K-SALT equation demonstrated the highest concordance ($r = 0.44$; 95% CI: 0.38–0.50) compared with the Kawasaki ($r = 0.34$; 95% CI: 0.25–0.38), Tanaka ($r = 0.34$; 95% CI: 0.27–0.41), INTERSALT ($r = 0.36$; 95% CI: 0.29–0.42), and Nerbass ($r = 0.31$; 95% CI: 0.26–0.35) equations (Supplementary Table 2). In the external validation cohort, the K-SALT equation showed a lower

level of agreement ($r = 0.31$; 95% CI: 0.25–0.37) compared with the Kawasaki ($r = 0.32$; 95% CI: 0.25–0.39), and Tanaka ($r = 0.36$; 95% CI: 0.29–0.43) equations, yet it remained superior to the INTERSALT ($r = 0.24$; 95% CI: 0.18–0.29), and Nerbass ($r = 0.17$; 95% CI: 0.13–0.21) equations (Supplementary Table 3).

Reliability and Explanatory Performance of the Predictive Model

Model reliability and explanatory capacity were evaluated using the ICC and R^2 .

In the internal validation cohort, the K-SALT equation showed the highest concordance between measured and estimated 24 hUNa excretion, with an ICC of 0.44 (95% CI: 0.37–0.51) and an R^2 of 0.26. In comparison, the ICC values of the Kawasaki, Tanaka, INTERSALT, and Nerbass equations were 0.31 (95% CI: 0.17–0.43), 0.34 (95% CI: 0.26–0.42), 0.36 (95% CI: 0.28–0.43), and 0.31 (95% CI: 0.05–0.49), respectively, and the corresponding R^2 values were 0.13, 0.13, 0.18, and 0.26 (Figure 5).

In the external validation, the K-SALT equation also demonstrated the most robust agreement (ICC, 0.31; 95% CI: 0.23–0.39; $R^2 = 0.18$), whereas the ICCs for the Kawasaki, Tanaka, INTERSALT, and Nerbass equations were 0.32 (95% CI: 0.16–0.45), 0.36 (95% CI: 0.28–0.44), 0.24 (95% CI: 0.15–0.32), and 0.17 (95% CI: 0.04–0.29), respectively, with R^2 values of 0.14, 0.17, 0.13, and 0.12 (Figure 6).

Table 6. Pearson correlation coefficients between measured and estimated 24-hour urinary sodium excretion (internal validation)

Variables	K-SALT		Kawasaki		Tanaka		INTERSALT		Nerbass	
	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P value	Coefficient (95% CI)	P value	Coefficient (95% CI)	P-value
All	0.52 (0.45–0.57) ^a	< 0.001	0.36 (0.29–0.44)	< 0.001	0.37 (0.29–0.44)	< 0.001	0.42 (0.35–0.49)	< 0.001	0.51 (0.45–0.57)	< 0.001
Sex										
Male	0.51 (0.42–0.58)	< 0.001	0.32 (0.22–0.41)	< 0.001	0.32 (0.22–0.42)	< 0.001	0.40 (0.30–0.49)	< 0.001	0.50 (0.42–0.58)	< 0.001
Female	0.47 (0.35–0.57)	< 0.001	0.43 (0.31–0.54)	< 0.001	0.45 (0.33–0.55)	< 0.001	0.42 (0.30–0.53)	< 0.001	0.46 (0.34–0.56)	< 0.001
Age										
≥ 65	0.52 (0.41–0.61)	< 0.001	0.39 (0.27–0.49)	< 0.001	0.38 (0.26–0.549)	< 0.001	0.38 (0.25–0.49)	< 0.001	0.51 (0.40–0.60)	< 0.001
< 65	0.50 (0.41–0.58)	< 0.001	0.35 (0.25–0.44)	< 0.001	0.36 (0.26–0.45)	< 0.001	0.45 (0.36–0.53)	< 0.001	0.51 (0.42–0.59)	< 0.001
BMI (kg/m ²)										
≥ 25	0.43 (0.32–0.53)	< 0.001	0.33 (0.21–0.43)	< 0.001	0.31 (0.19–0.42)	< 0.001	0.36 (0.25–0.46)	< 0.001	0.40 (0.29–0.50)	< 0.001
18.5 ≤ < 25	0.42 (0.32–0.52)	< 0.001	0.34 (0.23–0.45)	< 0.001	0.37 (0.26–0.47)	< 0.001	0.33 (0.21–0.44)	< 0.001	0.43 (0.32–0.52)	< 0.001
< 18.5	0.50 (0.11–0.76)	0.02	0.32 (-0.11 to 0.65)	0.14	0.32 (-0.11 to 0.65)	0.14	0.20 (-0.23 to 0.56)	0.37	0.39 (-0.02 to 0.69)	0.39
eGFR (ml/min per 1.73 m ²)										
≥ 90	0.52 (0.38–0.64)	< 0.001	0.37 (0.20–0.51)	< 0.001	0.39 (0.22–0.53)	< 0.001	0.49 (0.34–0.62)	< 0.001	0.55 (0.41–0.66)	< 0.001
60 ≤ < 90	0.43 (0.30–0.55)	< 0.001	0.35 (0.20–0.48)	< 0.001	0.32 (0.17–0.45)	< 0.001	0.45 (0.31–0.56)	< 0.001	0.42 (0.28–0.54)	< 0.001
30 ≤ < 60	0.52 (0.41–0.62)	< 0.001	0.39 (0.25–0.50)	< 0.001	0.37 (0.24–0.49)	< 0.001	0.38 (0.26–0.50)	< 0.001	0.54 (0.42–0.63)	< 0.001
< 30	0.54 (0.33–0.70)	< 0.001	0.32 (0.07–0.53)	0.01	0.36 (0.12–0.57)	0.01	0.32 (0.07–0.53)	0.01	0.46 (0.24–0.64)	< 0.001
24-h urine protein (mg/d)										
≥ 1000	0.43 (0.28–0.57)	< 0.001	0.35 (0.18–0.49)	< 0.001	0.34 (0.18–0.49)	< 0.001	0.43 (0.28–0.57)	< 0.001	0.52 (0.38–0.64)	< 0.001
500 ≤ < 1000	0.56 (0.39–0.69)	< 0.001	0.43 (0.24–0.59)	< 0.001	0.47 (0.28–0.63)	< 0.001	0.40 (0.20–0.57)	< 0.001	0.57 (0.40–0.70)	< 0.001
< 500	0.52 (0.44–0.60)	< 0.001	0.39 (0.29–0.48)	< 0.001	0.37 (0.27–0.46)	< 0.001	0.40 (0.30–0.49)	< 0.001	0.48 (0.39–0.56)	< 0.001
24-h urine sodium (mEq/d)										
≥ 150	0.33 (0.21–0.44)	< 0.001	0.22 (0.09–0.34)	< 0.001	0.22 (0.09–0.34)	0.50	0.29 (0.17–0.41)	< 0.001	0.34 (0.22–0.45)	< 0.001
100 ≤ < 150	0.11 (-0.05 to 0.26)	0.18	-0.09 (-0.24 to 0.07)	0.28	-0.09 (-0.24 to 0.07)	0.27	-0.03 (-0.19 to 0.13)	0.71	0.15 (0.00–0.30)	0.06
< 100	0.26 (0.10–0.41)	0.01	0.27 (0.11–0.41)	0.01	0.27 (0.11–0.42)	< 0.001	0.12 (-0.04 to 0.28)	0.14	0.21 (0.05–0.36)	0.01

BMI, body mass index; CI, confidence interval; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool.

^aIndicates that the predictive performance is significantly better than that of the other equations.

Table 7. Pearson correlation coefficients between measured and estimated 24-h urinary sodium excretion (external validation)

Variables	K-SALT		Kawasaki		Tanaka		INTERSALT		Nerbass	
	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P-value	Coefficient (95% CI)	P-value
All	0.43 (0.35–0.50) ^a	< 0.001	0.38 (0.30–0.45)	< 0.001	0.41 (0.33–0.48)	< 0.001	0.36 (0.28–0.44)	< 0.001	0.35 (0.27–0.42)	< 0.001
Sex										
Male	0.47 (0.37–0.56)	< 0.001	0.39 (0.28–0.49)	< 0.001	0.44 (0.34–0.54)	< 0.001	0.41 (0.30–0.50)	< 0.001	0.35 (0.24–0.45)	< 0.001
Female	0.37 (0.25–0.48)	< 0.001	0.35 (0.23–0.47)	< 0.001	0.38 (0.25–0.449)	< 0.001	0.36 (0.23–0.47)	< 0.001	0.30 (0.17–0.42)	< 0.001
Age										
≥ 65	0.50 (0.37–0.60)	< 0.001	0.46 (0.33–0.57)	< 0.001	0.47 (0.35–0.58)	< 0.001	0.40 (0.26–0.52)	< 0.001	0.42 (0.29–0.54)	< 0.001
< 65	0.33 (0.23–0.43)	< 0.001	0.32 (0.22–0.42)	< 0.001	0.37 (0.27–0.47)	< 0.001	0.34 (0.24–0.44)	< 0.001	0.33 (0.23–0.43)	< 0.001
BMI (kg/m ²)										
≥ 25	0.41 (0.29–0.52)	< 0.001	0.30 (0.17–0.42)	< 0.001	0.31 (0.18–0.43)	< 0.001	0.29 (0.16–0.41)	< 0.001	0.28 (0.15–0.40)	< 0.001
18.5 ≤ < 25	0.41 (0.29–0.51)	< 0.001	0.39 (0.28–0.50)	< 0.001	0.43 (0.32–0.53)	< 0.001	0.39 (0.27–0.49)	< 0.001	0.42 (0.31–0.52)	< 0.001
< 18.5	0.55 (0.29–0.73)	< 0.001	0.60 (0.36–0.77)	< 0.001	0.65 (0.42–0.80)	< 0.001	0.57 (0.32–0.75)	< 0.001	0.58 (0.34–0.76)	< 0.001
eGFR (ml/min per 1.73 m ²)										
≥ 90	0.44 (0.30–0.56)	< 0.001	0.35 (0.20–0.49)	< 0.001	0.43 (0.28–0.56)	< 0.001	0.43 (0.29–0.56)	< 0.001	0.35 (0.20–0.49)	< 0.001
60 ≤ < 90	0.44 (0.26–0.60)	< 0.001	0.44 (0.26–0.60)	< 0.001	0.45 (0.27–0.60)	< 0.001	0.32 (0.13–0.50)	< 0.001	0.36 (0.17–0.53)	< 0.001
30 ≤ < 60	0.34 (0.19–0.48)	< 0.001	0.27 (0.11–0.41)	0.01	0.28 (0.12–0.43)	< 0.001	0.30 (0.14–0.44)	< 0.001	0.33 (0.18–0.47)	< 0.001
< 30	0.41 (0.23–0.55)	< 0.001	0.48 (0.31–0.61)	< 0.001	0.44 (0.27–0.59)	< 0.001	0.33 (0.15–0.49)	< 0.001	0.44 (0.28–0.59)	< 0.001
24-h urine sodium (mEq/d)										
≥ 150	0.21 (0.07–0.33)	0.01	0.33 (0.20–0.45)	< 0.001	0.33 (0.20–0.45)	< 0.001	0.23 (0.09–0.36)	0.01	0.16 (0.02–0.29)	0.03
100 ≤ < 150	0.16 (-0.03 to 0.34)	0.11	0.17 (-0.02 to 0.34)	0.09	0.16 (-0.03 to 0.34)	0.10	0.11 (-0.08 to 0.29)	0.25	0.10 (-0.09 to 0.28)	0.30
< 100	0.35 (0.21–0.48)	< 0.001	0.20 (0.05–0.34)	0.01	0.29 (0.14–0.42)	< 0.001	0.29 (0.15–0.42)	< 0.001	0.23 (0.08–0.37)	0.01

BMI, body mass index; CI, confidence interval; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool.

^aIndicates that the predictive performance is significantly better than that of the other equations.

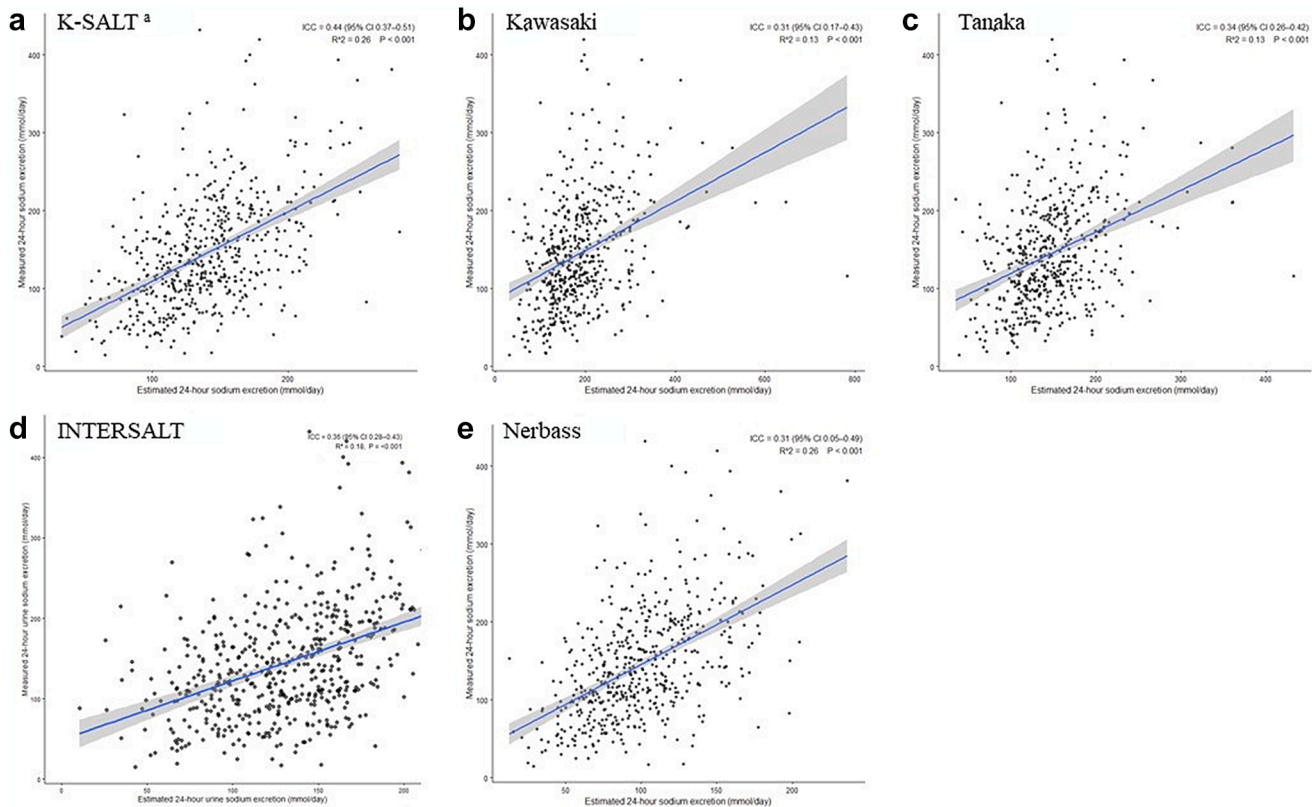


Figure 5. Scatter plots of measured 24-hour urine Na excretion and estimated 24-hour urine Na excretion by (a) K-SALT, (b) Kawasaki, (c) Tanaka, (d) INTERSALT, (e) Nerbass equation (Internal validation). ^aIndicates that the predictive performance is significantly better than that of the other equations.

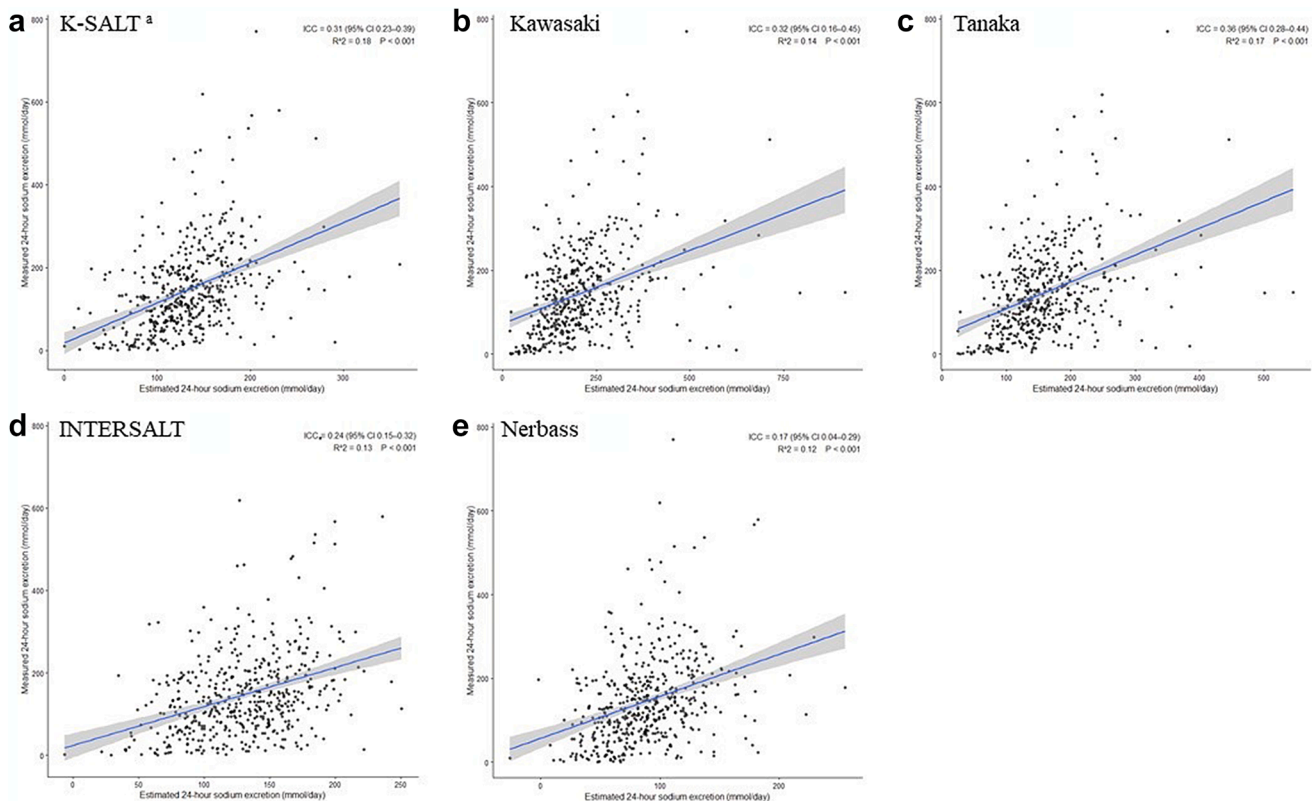


Figure 6. Scatter plots of measured 24-hour urine Na excretion and estimated 24-hour urine Na excretion by (a) K-SALT, (b) Kawasaki, (c) Tanaka, (d) INTERSALT, and (e) Nerbass equation (external validation). ^aIndicates that the predictive performance is significantly better than that of the other equations.

Discriminative Performance for Identifying High Sodium Excretion

The discriminative capability of the novel equation to identify individuals with high sodium excretion (≥ 150 mEq/day) was evaluated using ROC analysis.

In the internal validation, the K-SALT equation achieved a highest AUC of 0.74 (95% CI: 0.70–0.79), comparable to the Nerbass equation (AUC = 0.75; 95% CI: 0.71–0.79) and superior to those of the Kawasaki (AUC = 0.69; 95% CI: 0.64–0.73), Tanaka (AUC = 0.68; 95% CI: 0.63–0.73), and INTERSALT (AUC = 0.71; 95% CI: 0.66–0.76) equations (Figure 7a). In subgroup analysis, the K-SALT equation showed consistently higher sensitivity across thresholds and maintained stable accuracy in patients with impaired renal function (AUC = 0.76–0.79) (Figure 7b–d).

In the external validation, the K-SALT equation also showed strong discriminative performance, with an AUC of 0.73 (95% CI: 0.69–0.78), outperforming those of the Kawasaki (0.69; 95% CI: 0.64–0.74), Tanaka (0.69; 95% CI: 0.64–0.74), INTERSALT (0.66; 95% CI: 0.61–0.71), and Nerbass (0.69; 95% CI: 0.64–0.73) equations (Figure 8a). When stratified by kidney function, the discriminative performance of K-SALT equation remained consistent, with AUCs of 0.71 for $\text{eGFR} < 60$ mL/min per 1.73 m^2 , 0.66 for $\text{eGFR} < 45$ mL/min per 1.73 m^2 , and 0.71 for $\text{eGFR} < 30$ mL/min per 1.73 m^2 (Figure 8b–d).

DISCUSSION

This study was initiated and coordinated by the Social Contribution Committee of the Korean Society of Nephrology as part of its nationwide effort to promote evidence-based public health strategies for low salt diet.¹⁴ We developed and validated a novel equation, the Korean Sodium Assessment Tool for 24-hUNa using spot urine (K-SALT) equation, to estimate 24 hUNa excretion using routinely obtainable clinical and laboratory parameters. Incorporating 8 predictors (age, sex, height, weight, spot urine sodium, spot urine potassium, spot urine creatinine, and serum creatinine), the K-SALT equation demonstrated higher reliability and explanatory power than conventional equations in both internal and external validation datasets.

The validity of estimating 24 hUNa from spot urine samples has long been debated. Multiple studies have shown wide variability in correlation strength across populations because of differences in dietary habits, diurnal sodium excretion, and kidney function heterogeneity.^{15–17} When applied to our cohort, previously established equations (Kawasaki, Tanaka, INTERSALT, and Nerbass) exhibited their limited applicability in CKD populations. In contrast, the K-SALT equation, developed entirely within a CKD population encompassing all GFR strata, inherently reflects disease-specific sodium and creatinine

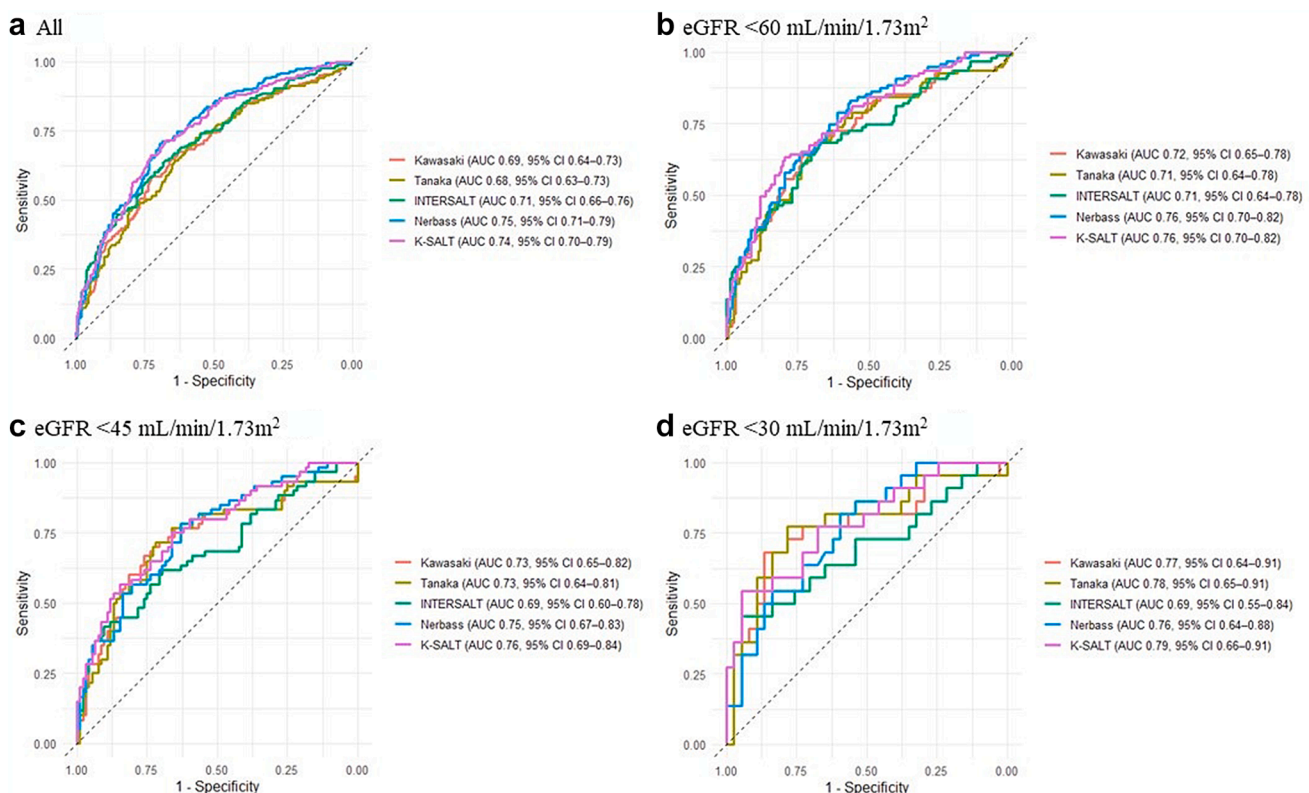


Figure 7. ROC curves for predicting 24-hour urine sodium ≥ 150 mEq/day (internal validation). AUC, area under the curve; CI, confidence interval; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool; ROC, receiver operating characteristic.

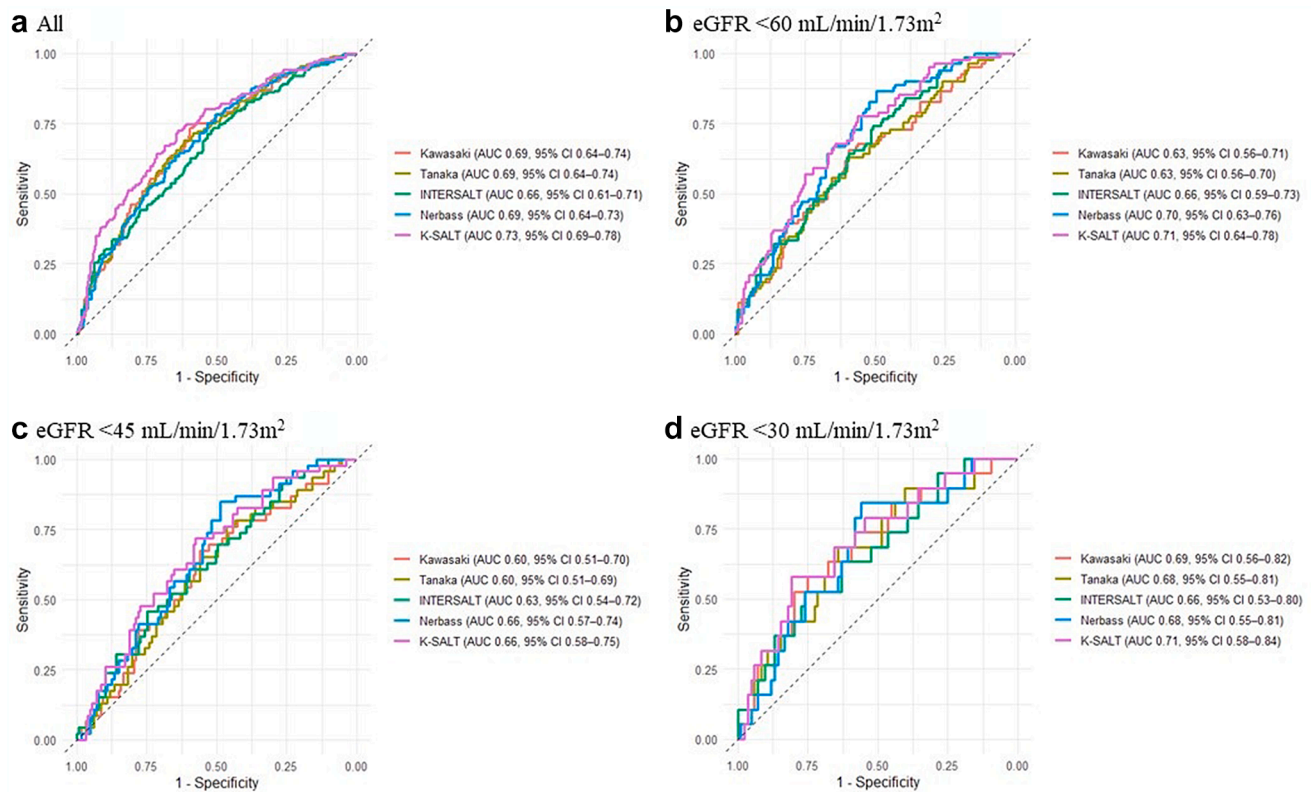


Figure 8. ROC curves for predicting 24-hour urine sodium ≥ 150 mEq/day (external validation). AUC, area under the curve; CI, confidence interval; eGFR, estimated glomerular filtration rate; K-SALT, Korean sodium assessment tool; ROC, receiver operating characteristic.

handling. Moreover, the inclusion of serum creatinine provides adjustment for renal filtration capacity, improving performance among patients with advanced CKD (eGFR < 30 mL/min per 1.73 m²). This CKD-based derivation and validation process fundamentally differentiates K-SALT equation from previous proposed formulas and supports its robust applicability in nephrology practice.

It is noteworthy that the K-SALT equation demonstrated moderate correlation and discriminative power. Although these values may not represent perfect individual-level prediction, they are consistent with the performance of spot urine-based methods reported in previous literature. The inherent biological variability in sodium intake, significant diurnal fluctuations in excretion, and the impact of CKD on urine concentration make high precision estimation from a single spot sample naturally challenging. However, from a practical standpoint, the primary objective of the K-SALT equation is not to replace the 24-hr urine gold standard, but to provide a more reliable and accessible tool for monitoring sodium intake trends when complete collection is unfeasible. By achieving smaller mean bias and higher concordance than existing formulas across all GFR strata, K-SALT offers enhanced clinical utility for identifying high-

risk individuals and guiding longitudinal dietary management in the Korean CKD population.

Excessive sodium intake is a well-established risk factor for hypertension, cardiovascular events, and CKD progression.^{1,18–22} Reliable estimation of sodium excretion from standard tests could support individualized dietary counseling, volume management, and population-level surveillance. From a clinical perspective, the availability of a validated spot urine-based tool may also help clinicians overcome practical barriers associated with 24-hour urine collection, facilitating more frequent and individualized monitoring of sodium intake in routine care. Accurate assessment of sodium intake plays a pivotal role in optimizing cardiovascular and kidney outcomes by facilitating individualized dietary counseling and education.^{23–25} The consistent performance of the K-SALT equation across internal and external validation cohorts reinforces its clinical applicability. Although previous equations have often shown reduced performance in external validation cohort, the K-SALT equation maintained comparable ICC, R^2 , and AUC values, confirming robustness to demographic and physiological heterogeneity.

Methodologically, the K-SALT equation was developed using a log-transformed linear regression framework, which ensured proportional estimation and eliminated intercept-related bias. This approach offers

interpretability and reproducibility, allowing direct quantification of each variable's contribution to the overall estimate. Compared with complex machine-learning models that may overfit or lack generalizability, linear regression ensures stability and facilitates clinical integration. Its simplicity and reliance on routinely available parameters also make the model easily applicable within electronic health records and bedside decision-support systems.

This study has several notable strengths. It represents the largest multicenter study in Korea to estimate 24 hUNa excretion in patients with CKD, incorporating both a prospectively derived development cohort and an independently established external validation cohort. The inclusion of routinely collected clinical and laboratory parameters enhances the model's clinical practicality and facilitates its integration into real-world nephrology practice. Furthermore, rigorous validation across distinct cohorts provides strong support for the robustness and generalizability of the K-SALT equation.

Nevertheless, several limitations should be acknowledged. First, the Bland–Altman analysis revealed relatively wide limits of agreement, indicating that the K-SALT equation's precision for absolute individual-level prediction is constrained by the inherent biological variability and circadian rhythm of sodium excretion. Consequently, whereas our model provides the lowest mean bias and improved discriminative power compared with existing formulas, it should be used as a practical tool for monitoring intake trends and identifying high-risk groups rather than as a definitive replacement for 24-hour urine collection in precise clinical quantification. In addition to these inherent physiological constraints, incomplete or inaccurate urine collection cannot be completely excluded despite standardized protocols. The external validation cohort, though independent, included fewer advanced CKD cases. Additionally, diurnal variation and dietary diversity were not fully captured, and longitudinal associations with clinical outcomes remained beyond the scope of this study. Furthermore, because regression-based prediction equations are influenced by the characteristics of the development cohort, the performance of the K-SALT equation may vary across different populations and change over time as dietary patterns and clinical environments evolve. This underscores the potential need for periodic recalibration and further validation in diverse external cohorts to ensure its continued reliability. Lastly, as this study was conducted exclusively in a Korean population, the K-SALT equation requires explicit validation in non-Korean populations to confirm its generalizability and broader clinical applicability.

In conclusion, the K-SALT equation offers a practical and physiologically appropriate method for estimating 24 hUNa excretion in Korean patients with CKD. Its consistency across kidney function strata indicates potential applicability in routine clinical assessment and in population-based evaluation of sodium intake. Future prospective studies are warranted to assess its longitudinal impact and external generalizability.

DISCLOSURE

All the authors declared no competing interests.

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DATA AVAILABILITY STATEMENT

The individual-level clinical data supporting the findings of this study are not publicly available because of participant privacy but can be shared upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

The conceptualization of this study was done by JYJ; Data curation by SC, HCP, WYP, SRK, YCK, HR, SP, CHB, SHS, SYA, JNA, JL, CSL, HL, HC, J-YC, SDH, JHH, JIP, and JYJ; and formal analysis by SC and JYJ. The funding acquisition was contributed by JYJ; supervision by HCP and JYJ; and methodology by SC and JYJ. Data interpretation was done by all authors; Writing the original draft by SC; and writing-review and editing by SC and JYJ. All authors read and approved the final manuscript.

SUPPLEMENTARY MATERIAL

[Supplementary file \(PDF\)](#)

Table S1. Baseline characteristics of external validation cohort

Table S2. Lin's concordance correlation coefficients between measured and estimated 24-hour urinary sodium excretion (internal validation)

Table S3. Lin's concordance correlation coefficients between measured and estimated 24-hour urinary sodium excretion (external validation)

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