


## Measured sodium excretion is associated with CKD progression: results from the KNOW-CKD study

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### ABSTRACT

**Background.** Diet is a modifiable factor of chronic kidney disease (CKD) progression. However, the effect of dietary salt intake on CKD progression remains unclear. Therefore, we analyzed the effect of dietary salt intake on renal outcome in Korean patients with CKD.

**Methods.** We measured 24-h urinary sodium (Na) excretion as a marker of dietary salt intake in the prospective, multi-center, longitudinal KoreaN cohort study for Outcome in patients With CKD (KNOW-CKD). Data were analyzed from CKD patients at Stages G3a to G5 ( $n = 1254$ ). We investigated the association between dietary salt intake and CKD progression. Patients were divided into four quartiles of dietary salt intake, which was assessed using measured 24-h urinary Na excretion. The study endpoint was composite renal outcome, which was defined as either halving the estimated glomerular filtration rate or developing end-stage renal disease.

**Results.** During a median (interquartile range) follow-up of 4.3 (2.8–5.8) years, 480 (38.7%) patients developed the composite renal event. Compared with the reference group (Q2, urinary Na excretion:  $104.2 \leq \text{Na excretion} < 145.1$  mEq/day), the highest quartile of measured 24-h urinary Na excretion was associated with risk of composite renal outcome [Q4, urinary Na excretion  $\geq 192.9$  mEq/day, hazard ratio 1.8 (95% confidence interval 1.12–2.88);  $P = 0.015$ ] in a multivariable hazards model. Subgroup analyses showed that high-salt intake was particularly associated with a higher risk of composite renal outcome in women, in patients  $< 60$  years of age, in those with uncontrolled hypertension and in those with obesity.

**Conclusions.** High salt intake was associated with increased risk of progression in CKD.

**Keywords:** chronic kidney disease, dietary salt intake, renal progression

### INTRODUCTION

Lifestyle in general, and particularly diet, is a modifiable risk factor for chronic kidney disease (CKD) progression [1]. CKD itself is a risk factor for cardiovascular diseases and death [2]. Therefore, it is important to prevent CKD progression in its early stages [3, 4]. We focused on educating patients on their dietary habits, which are modifiable factors in the treatment of CKD.

The average salt intake in patients with CKD from the USA, the Netherlands, the UK, Turkey, Italy, Australia, Denmark and Korea was 9.5 g/day [5]. The average salt intake in general populations of the USA, the UK, Japan, China, Italy, Belgium, Finland, Germany, New Zealand and the Netherlands was 9.9 g/day [6]. Because of the detrimental effects of high-salt intake on blood pressure and cardiovascular disease [7, 8], many countries have attempted to reduce average salt intake [9]. According to the Korea National Health and Nutrition Examination Survey [10], the average daily salt intake in Koreans decreased from 11.0 to 8.3 g over the last 8 years. A person's diet is affected by region, socioeconomic status and culture [11–13]. Therefore, studies regarding diet and dietary guidelines must reflect the characteristics of respective races and cultures.

The current guidelines recommend <5 g of salt intake per day [14]. This guideline is based on studies showing that salt restriction reduced blood pressure and proteinuria [15, 16]. However, these studies did not analyze renal outcomes associated with a high salt diet, such as incident end-stage renal disease (ESRD) or estimated glomerular filtration rate (eGFR) halving. Therefore, there is insufficient evidence that high-salt diet is associated with CKD progression.

A few studies, including the Chronic Renal Insufficiency Cohort (CRIC) study, have demonstrated a significant association between high salt intake and CKD progression in patients with CKD [17–19]. In contrast, other studies have shown no association between urinary sodium (Na) excretion and kidney failure in CKD patients [20, 21]. However, most of these previous studies are not generalizable to the entire CKD population because they were performed in specific subgroups of CKD subjects, such as nondiabetic CKD, diabetic CKD or advanced CKD patients (eGFR <30 mL/min/1.73 m<sup>2</sup>). The CRIC study covers the entire CKD population, however, the race is mostly Caucasian and African Americans. Therefore, it is difficult to apply the results directly to the Asian CKD population.

Meanwhile, in the general population, a U-shaped relationship was shown between salt diet and incident CKD only in the group with hypertension (HTN) [22]. Therefore, the effect of urinary Na excretion on CKD progression remains controversial not only in the general population, but also in CKD patients.

This study analyzed patients with variable etiologies of CKD. We sought to demonstrate the effect of dietary salt intake, as assessed by measured 24-h urinary Na excretion, on renal outcomes in CKD patients using a dataset from a prospective CKD cohort, entitled the KoreaN cohort study for Outcome in patients With CKD (KNOW-CKD).

## MATERIALS AND METHODS

### Study participants

KNOW-CKD cohort is an ongoing nationwide, multicenter, prospective cohort study from nine tertiary hospitals in Korea [23, 24]. Between 2011 and 2016, a total of 2238 patients with CKD Stages 1–5 (predialysis) and aged between 20 and 75 years old was enrolled. Patients with previous history of dialysis, any organ transplant, heart failure (the New York Heart Association (NYHA) functional classification III or IV), known cirrhosis, history of cancer and pregnant women were excluded. At enrollment, the subjects collected 24-h urine samples for Na excretion. Because patients with relatively preserved kidney function tended to follow a high salt diet [17], we excluded subjects with eGFR ≥60 mL/min/1.73 m<sup>2</sup> ( $n = 785$ ). Patients were also excluded if they did not collect 24-h urine specimens successfully ( $n = 4$ ), did not have baseline 24-h urinary Na excretion ( $n = 186$ ) or had extreme urinary sodium excretion (>1000 mEq/day or <20 mEq/day) ( $n = 9$ ). Ultimately, 1254 patients were included (Supplementary data, Figure S1). These patients were divided according to quartile of measured 24-h urinary Na excretion. The study design was approved by the

interstitial review boards of the participating centers and complies with the Declaration of Helsinki.

### Data collection and measurements

Information regarding patient demographic characteristics, medical history and medications was collected by self-report and review of the medical records. The baseline laboratory data included hemoglobin, serum albumin, creatinine, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C) and triglyceride. The measured 24-h urinary Na excretion was used to assess daily salt intake [25]. Urine samples that were collected inadequately (urine <500 mL/day) were excluded. For sensitivity analysis, spot urinary samples were used for Na and creatinine concentrations. Patients were excluded from sensitivity analysis if they did not have baseline spot urinary samples ( $n = 38$ ). The Tanaka equation was used to estimate 24-h urinary Na excretion from spot urine Na [26]. The formula is:  $21.98 \times ([\text{spot Na (mmol/L)}/\text{spot Cr (mg/dL)} \times 10] \times \{[-2.04 \times \text{age (years)}] + [14.89 \times \text{weight (kg)}] + [16.14 \times \text{height (cm)}] - 2244.45\})^{0.392}$ . Serum creatinine was measured using an isotope dilution mass spectrometry-calibrated method at a central laboratory. The eGFR was calculated by the CKD Epidemiology Collaboration equation [27]. Random urine sodium and creatinine were measured at a central laboratory. Uncontrolled HTN was defined as systolic blood pressure (SBP) ≥130 mmHg or diastolic blood pressure (DBP) ≥80 mmHg [28]. Body weight (BW)-adjusted dietary protein intake (DPI) was defined as estimated DPI/BW (g/day/kg BW), wherein estimated DPI was  $6.25 \times [24\text{-h urinary urea (mg/day)}/1000 + 0.03 \times \text{BW (kg)}] + [24\text{-h urinary protein (mg/day)}/1000]$  [29]. The recommended dietary allowance was a BW-adjusted DPI ≥0.8 g/day/kg BW [30].

### Outcomes

The primary outcome was the composite renal outcome, which was defined as eGFR halving or occurrence of ESRD. ESRD was defined as initiation of dialysis or kidney transplantation. The subjects who were lost to follow-up were censored at the time of last visit. Survival time was calculated from enrollment to occurrence of the event or the last follow-up.

### Statistical analysis

All statistical analyses were performed with SPSS software version 25 (IBM Corp., Armonk, NY, USA) and R software version 3.5.3 (www.r-project.org; R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were expressed as mean ± standard deviation or as medians with interquartile ranges (IQRs). The Kolmogorov–Smirnov test was employed for the normality test. Categorical variables were expressed as numbers and percentages. To compare the clinical characteristics according to quartile of urinary sodium excretion, one-way analysis of variance was used for continuous variables (Kruskal–Wallis test if not applicable), while the Chi-squared test was used for categorical variables (Fisher's exact test if not applicable). To calculate the P for trend, the

Jonckheere–Terpstra test was employed for continuous variables, and the Linear-by-Linear Association was employed for categorical variables. The hazard ratio (HR) of the composite renal outcome was analyzed using Cox proportional hazards models. Multiple covariables were adjusted. In Model 1, we adjusted for demographic information such as age, sex, body mass index (BMI) and baseline urinary creatinine. In Model 2, we further adjusted for risk factors of CKD such as urinary potassium excretion and baseline eGFR. Model 3 adjusted for CKD etiology, the presence of diabetes mellitus (DM), medications [such as diuretics and renin–angiotensin system (RAS) blockers], urinary protein excretion and SBP, in addition to factors included in Model 2. A cubic spline curve was used to explore the association between urinary Na excretion and CKD progression. The same multivariable models were applied to the cubic spline curves. Subgroup analyses were performed with respect to age group, sex, baseline eGFR, uncontrolled HTN, DM, obesity (BMI  $\geq 25$  kg/m<sup>2</sup>), use of RAS blockers, use of diuretics, 24-h urinary potassium excretion and proteinuria. Spearman correlation analysis was used to estimate the correlation between urinary Na excretion and blood pressure.  $P < 0.05$  were considered statistically significant.

## RESULTS

### Baseline characteristics

The baseline characteristics are shown in Table 1 according to quartiles of measured 24-h urinary Na excretion. The median (IQR) patient age was 58.0 years (50.0–66.0), and the majority (62.0%) was male. Most patients (98.6%) also had a diagnosis of HTN. Subjects with higher urinary Na excretion tended to be male ( $P$  for trend  $< 0.001$ ) (Table 1). Subjects with a lower eGFR category tended to have lower urinary Na excretion ( $P$  for trend  $< 0.001$ ) (Table 1, Supplementary data, Figure S2). SBP and BMI increased with Na excretion. There were also more diabetic patients with higher urinary Na excretion than there were nondiabetic patients ( $P$  for trend = 0.012). Higher urinary Na excretion is associated with higher weight-adjusted DPI  $\geq 0.8$  g/day/kg and potassium intake ( $P$  for trend  $< 0.001$ ), meaning that they are eating more. Urinary excretions of creatinine, protein and chloride increased as urinary Na excretion increased. A positive correlation showed that between measured 24-h urinary sodium excretion and mean blood pressure ( $R^2$  Linear = 0.012,  $P = 0.002$ ) (Supplementary data, Figure S3).

### Renal outcomes

During a median (IQR) follow-up of 4.3 years (2.8–5.8 years), 480 (38.7%) patients developed the composite renal outcome. The incidence rates of the composite renal outcome from the lowest to the highest quartile of measured 24-h urinary Na excretion were 140.2, 97.6, 116.6 and 117.8 per 1000 person-years, respectively. The adjusted HRs (95% confidence intervals) of the composite renal outcome (compared with that of the second quartile) were 1.28 (0.84–1.98), 1.69 (1.08–2.65) and 1.80 (1.12–2.88) for the first, third and fourth quartiles of urinary Na excretion, respectively (Model 3 in Table 2). The

spline curve clearly demonstrated a relatively linear relationship between measured 24-h urinary Na excretion and risk of composite renal outcomes at the reference of urinary Na excretion  $\geq 120.0$  mEq/day (Figure 1). At measured 24-h urinary Na excretion  $\geq 120.0$  mEq/day, for every 100 mEq increase in daily urinary Na excretion, the risk of composite renal outcomes increased by 1.55 times in multivariable Cox regression analysis (Supplementary data, Table S1). Meanwhile, low urinary Na excretion (the lowest quartile) was not significantly associated with risk of the composite renal outcome (Table 2).

### Subgroup analyses

The risk of the highest quartile of measured 24-h urinary Na excretion was compared with the risk of the second quartile of urinary Na excretion by subgroup stratified according to age ( $< 60$  or  $\geq 60$  years old), sex (male or female), eGFR ( $< 45$  or  $\geq 45$  mL/min/1.73 m<sup>2</sup>), uncontrolled HTN (with or without), DM (with or without), obesity (BMI  $\geq 25$  or  $< 25$  kg/m<sup>2</sup>), use of RAS blockers (yes or no), use of diuretics (yes or no), urinary potassium excretion ( $< 37$  or  $\geq 37$  mEq/day) and proteinuria ( $< 3.5$  or  $\geq 3.5$  g/day). The highest measured 24-h urinary Na excretion was strongly correlated with higher risks of the composite renal outcome. This was particularly true in subgroups  $< 60$  years, women and those with a lower eGFR ( $< 45$  mL/min/1.73 m<sup>2</sup>), uncontrolled HTN, obesity, use of RAS blockers or use of diuretics (Figure 2).

### Sensitivity analyses

We used the Tanaka equation to perform sensitivity analysis of estimated 24-h urinary Na excretion (calculated from spot urinary Na) in 1200 patients [26]. Estimated 24-h urinary Na excretion was divided into four groups for which the cut-off values were defined using primary analysis. When Cox regression analysis was employed, the risk of the fourth group was 1.96 times higher than the second group, which was the reference group (Model 3 in Supplementary data, Table S2). There was no significant association between the lowest urinary Na excretion and risk of renal outcome.

## DISCUSSION

Although salt intake is a modifiable factor of CKD, the effect of salt intake on renal outcome is unclear. Our long-term analysis of CKD patients found that the risk of composite renal outcome was 1.8-fold higher in patients with the highest degree of dietary salt intake (fourth quartile with measured 24-h urinary Na excretion  $\geq 192.9$  mEq/day) than in the reference group (104.2 mEq/day  $\leq$  urinary Na excretion  $< 145.1$  mEq/day). However, there was no difference in composite renal outcome between the first and second quartiles. The risk of composite renal outcomes from high salt intake was particularly evident in subgroups of patients  $< 60$  years old, female, with lower eGFR ( $< 45$  mL/min/1.73 m<sup>2</sup>) or uncontrolled HTN, or obesity, or RAS blockers or diuretics.

A previous study from the CRIC showed a positive association between high salt intake and risk of composite renal outcome (as defined by incident ESRD or eGFR halving) [17].

Table 1. Baseline participant characteristics

| Variable  | Measured 24-h urinary Na excretion (mEq/day) |                     |                              |                              |                     | P for trend |
|---|--|---------------------|------------------------------|------------------------------|---------------------|-------------|
|   | Total<br>(n = 1254)                          | <104.2<br>(n = 314) | 104.2 to <145.1<br>(n = 313) | 145.1 to <192.9<br>(n = 313) | ≥192.9<br>(n = 314) |             |
| Age, years  | 58.0 (50.0–66.0)                             | 58.0 (50.0–66.0)    | 58.0 (50.0–66.0)             | 59.0 (51.0–66.0)             | 58.0 (48.0–65.0)    | 0.293       |
| Male, n (%)                                       | 778 (62.0)                                   | 168 (53.5)          | 179 (57.2)                   | 195 (62.3)                   | 236 (75.2)          | <0.001      |
| Etiology of CKD, n (%)                            |  |                     |                              |                              |                     | 0.345       |
| Glomerulonephritis                                | 360 (28.7)                                   | 93 (29.6)           | 92 (29.4)                    | 94 (30.0)                    | 81 (25.8)           | –           |
| Diabetic nephropathy                              | 402 (32.1)                                   | 98 (31.2)           | 100 (31.9)                   | 95 (30.4)                    | 109 (34.7)          | –           |
| Hypertensive nephropathy                          | 290 (23.1)                                   | 75 (23.9)           | 65 (20.8)                    | 77 (24.6)                    | 73 (23.2)           | –           |
| Polycystic kidney disease                         | 129 (10.3)                                   | 32 (10.2)           | 43 (13.7)                    | 26 (8.3)                     | 28 (8.9)            | –           |
| Others  | 73 (5.8)                                     | 16 (5.1)            | 13 (4.2)                     | 21 (6.7)                     | 23 (7.3)            | <0.001      |
| eGFR category, mL/min/1.73 m <sup>2</sup> , n (%) |  |                     |                              |                              |                     | –           |
| 45–59   | 322 (25.7)                                   | 61 (19.4)           | 93 (29.7)                    | 77 (24.6)                    | 91 (29.0)           | –           |
| 30–44   | 410 (32.7)                                   | 91 (29.0)           | 94 (30.0)                    | 112 (35.8)                   | 113 (36.0)          | –           |
| 15–29   | 406 (32.4)                                   | 117 (37.3)          | 102 (32.6)                   | 102 (32.6)                   | 85 (27.1)           | –           |
| <15   | 116 (9.3)                                    | 45 (14.3)           | 24 (7.7)                     | 22 (7.0)                     | 25 (8.0)            | –           |
| SBP, mmHg   | 128.0 (118.0–138.0)                          | 124.5 (114.0–136.0) | 128.0 (120.0–138.0)          | 128.0 (119.0–136.0)          | 130.0 (118.0–139.0) | 0.037       |
| DBP, mmHg   | 76.0 (69.0–83.0)                             | 74.0 (67.0–81.0)    | 77.0 (69.0–85.0)             | 76.0 (70.0–83.0)             | 77.0 (69.0–85.0)    | 0.012       |
| Uncontrolled HTN <sub>1</sub> , n (%)             | 354 (28.3)                                   | 75 (23.9)           | 89 (28.4)                    | 85 (27.2)                    | 105 (33.5)          | 0.015       |
| BMI, kg/m <sup>2</sup>                            | 24.5 (22.5–26.5)                             | 23.6 (21.3–25.6)    | 24.3 (22.1–26.1)             | 24.7 (23.0–26.8)             | 25.3 (23.6–27.7)    | <0.001      |
| Use of medication                                 |  |                     |                              |                              |                     | 0.056       |
| RAS blocker, n (%)                                | 1082 (86.3)                                  | 257 (81.8)          | 280 (89.5)                   | 266 (85.0)                   | 279 (88.9)          | 0.188       |
| Diuretics, n (%)                                  | 497 (39.6)                                   | 120 (38.2)          | 118 (37.7)                   | 124 (39.6)                   | 135 (43.0)          | 0.012       |
| Diabetes, n (%)                                   | 540 (43.1)                                   | 125 (39.8)          | 125 (39.9)                   | 136 (43.5)                   | 154 (49.0)          | 0.398       |
| HTN, n (%)  | 1235 (98.6)                                  | 309 (98.4)          | 306 (97.8)                   | 311 (99.4)                   | 309 (98.7)          | 0.508       |
| Cardiovascular disease, n (%)                     | 251 (20.0)                                   | 61 (19.4)           | 69 (22.0)                    | 66 (21.1)                    | 55 (17.5)           | <0.001      |
| DPI ≥ 0.8 g/day/kg, n (%)                         | 810 (67.7)                                   | 124 (41.2)          | 183 (62.9)                   | 231 (76.2)                   | 272 (90.1)          | <0.001      |
| Laboratory findings                               |  |                     |                              |                              |                     | <0.001      |
| eGFR, mL/min/1.73 m <sup>2</sup>                  | 33.7 (23.1–45.2)                             | 29.3 (19.5–40.9)    | 34.7 (23.8–47.2)             | 33.7 (24.6–44.8)             | 36.3 (24.7–47.0)    | <0.001      |
| Hemoglobin, g/dL                                  | 12.0 (10.8–13.6)                             | 11.6 (10.6–12.8)    | 12.0 (10.7–13.9)             | 12.2 (11.0–13.6)             | 12.6 (11.0–14.1)    | 0.198       |
| Albumin, g/dL                                     | 4.2 (3.9–4.4)                                | 4.2 (3.9–4.4)       | 4.2 (3.9–4.4)                | 4.1 (3.9–4.4)                | 4.2 (3.9–4.5)       | 0.001       |
| LDL-C, mg/dL                                      | 89.0 (71.0–111.0)                            | 84.0 (69.0–103.5)   | 93.0 (72.0–113.5)            | 89.0 (71.0–115.0)            | 91.0 (74.0–114.0)   | 0.883       |
| HDL-C, mg/dL                                      | 44.0 (36.0–54.2)                             | 45.0 (36.0–56.0)    | 44.0 (36.2–54.2)             | 44.0 (36.0–54.0)             | 44.0 (37.0–54.0)    | 0.001       |
| Triglyceride, mg/dL                               | 138.0 (96.0–204.0)                           | 127.5 (91.0–185.0)  | 134.0 (96.0–206.5)           | 144.5 (98.0–205.0)           | 144.0 (107.0–217.0) | <0.001      |
| Urine volume, mL                                  | 1810.0                                       | 1350.0              | 1700.0                       | 1900.0                       | 2400.0              | <0.001      |
| (1500.0–2300.0)                                   | (1000.0–1680.0)                              | (1450.0–2000.0)     | (1600.0–2200.0)              | (2070.0–2850.0)              |                     | <0.001      |
| Urinary creatinine, mg/day                        | 1100.0                                       | 856.0               | 1000.0                       | 1127.5                       | 1388.8              | <0.001      |
| (848.0–1396.5)                                    | (660.0–1110.0)                               | (803.0–1276.0)      | (937.0–1400.0)               | (1122.0–1610.4)              |                     | <0.001      |
| Urinary protein, mg/day                           | 745.5  | 555.0               | 652.7                        | 798.7                        | 1241.0              | <0.001      |
| (271.1–2076.5)                                    | (231.0–1518.5)                               | (192.8–1592.8)      | (338.0–2190.0)               | (374.0–3536.0)               |                     | <0.001      |
| Urinary sodium, mEq/day                           | 145.1 (104.0–193.0)                          | 80.0 (62.0–95.0)    | 124.6 (115.0–134.0)          | 164.9 (156.0–178.0)          | 226.9 (209.6–265.0) | <0.001      |
| Urinary potassium, mEq/day                        | 48.0 (34.0–63.0)                             | 33.0 (24.2–42.0)    | 44.5 (35.2–57.8)             | 51.8 (41.0–63.0)             | 64.7 (50.0–77.0)    | <0.001      |
| Urinary chloride, mEq/day                         | 141.0 (99.0–189.3)                           | 78.1 (60.0–94.0)    | 126.2 (112.0–138.0)          | 169.0 (153.0–183.5)          | 226.0 (204.0–263.3) | <0.001      |

Data are presented as median (IQR) unless otherwise indicated.

The range of the highest quartile was urinary Na excretion >194.6 mEq/day, which is similar to that in this study. However, as dietary patterns vary by race and culture, it is difficult to apply such findings, mostly based on Caucasian and African Americans, directly to Asians. Besides, in the CRIC study, when proteinuria was added as an adjustment variable, the significance of the association between urinary sodium excretion and CKD progression disappeared. In contrast, in this study, the significant association between measured 24-h

urinary sodium excretion and CKD progression was maintained, even after adjustment for proteinuria. This suggests that urinary sodium excretion is an independent factor for CKD progression in this study, aside from proteinuria. Such discrepancy between our study and CRIC study might be partly attributable to the higher incidence of composite renal event in our study (117.7/1000 person-years), as compared with that of the CRIC study (59.4/1000 person-years), resulting in higher statistical power. Other studies have shown

Table 2. Multivariable model for risk of composite renal outcome

| Measured urinary sodium excretion (mEq/day) | Number of participants | Number of events (%) | Model 1            |         | Model 2            |         | Model 3            |         |
|---|------------------------|----------------------|--------------------|---------|--------------------|---------|--------------------|---------|
|   |                        |                      | HR (95% CI)        | P-value | HR (95% CI)        | P-value | HR (95% CI)        | P-value |
| <104.2                                      | 308                    | 136 (44)             | 1.22 (0.94 – 1.59) | 0.140   | 0.93 (0.61 – 1.40) | 0.713   | 1.28 (0.84 – 1.98) | 0.255   |
| 104.2 ≤ <145.1                              | 312                    | 100 (32)             | 1 (Reference)      | —       | 1 (Reference)      | —       | 1 (Reference)      | —       |
| 145.1 ≤ <192.9                              | 310                    | 122 (39)             | 1.36 (1.04 – 1.77) | 0.027   | 1.36 (0.88 – 2.11) | 0.169   | 1.69 (1.08 – 2.65) | 0.022   |
| ≥192.9                                      | 310                    | 122 (39)             | 1.52 (1.14 – 2.01) | 0.004   | 1.64 (1.04 – 2.58) | 0.033   | 1.80 (1.12 – 2.88) | 0.015   |
| Total                                       | 1240                   | 480 (39)             | —                  | —       | —                  | —       | —                  | —       |

Model 1: adjusted for age, sex, BMI and urinary creatinine excretion.

Model 2: Model 1 plus urinary potassium excretion and baseline eGFR.

Model 3: Model 2 plus etiology of CKD, the presence of DM, use of diuretics, use of RAS blockers, urinary protein excretion and SBP.

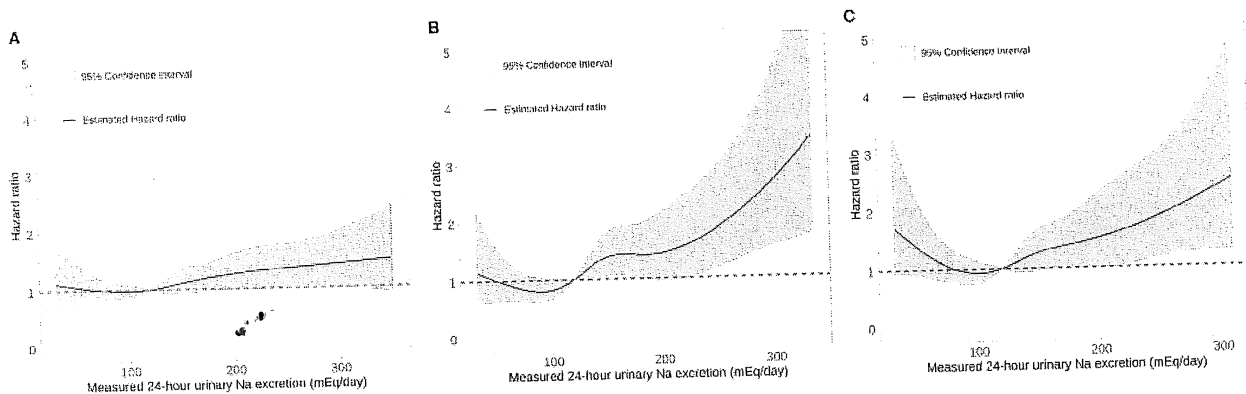


FIGURE 1: Association of measured 24-h urinary sodium excretion with HR of CKD progression in Model 1 (a), in Model 2 (b) and in Model 3 (c).

positive association between high-salt diet and CKD progression [18, 19, 31]. However, these studies were limited to a subgroup of CKD patients—proteinuric CKD without DM, CKD with Type 2 DM or to hypertensive CKD without DM. Meanwhile, other studies showed no association between urinary Na excretion and CKD progression in non-diabetic CKD patients [20] or in advanced CKD patients [21]. Overall, therefore, it has been controversial whether there is an association between salt intake and CKD progression. Besides, these prior findings were not generalizable to the overall CKD population.

In our study, risk of composite renal outcome in the highest quartile group (measured 24-h urinary Na excretion  $\geq 192.9$  mEq/day) was 1.8 times higher than that in the reference group. The first mechanistic explanation for this result is the positive association between urinary Na excretion and blood pressure, which is a risk factor of CKD progression [32, 33]. In particular, blood pressure was found to rise sharply in the high salt intake category (urinary Na excretion  $\geq 217.4$  mEq/day) of the general population [34]. In our analysis, the proportion of uncontrolled HTN was especially high in the highest quartile, and there was positive correlation between measured 24-h urinary Na excretion and mean blood pressure. Both CKD patients and those with HTN were salt-sensitive [35, 36]. In addition, most of our patients had HTN. Blood pressure increased sharply as daily salt intake increased, which might contribute to renal progression. Second, high salt intake attenuated the anti-proteinuric effect of RAS

blockers, which may contribute to poor renal outcome [18]. In our data, subgroup analyses showed that high salt intake was particularly associated with composite renal outcome in patients using RAS blockers. This result also supported the above explanation that the anti-proteinuric effect of RAS blockers in patients with high salt intake was attenuated. However, our analysis exhibited an independent association between high salt intake and renal progression, even after adjustment for blood pressure and proteinuria. Therefore, there might be another mechanism whereby high salt intake leads to kidney damage. One animal study showed that higher salt intake was associated with higher RAS activation and progression of renal fibrosis [37]. High salt intake increased inflammation [38] and oxidative stress [39]. Through the correlation between salt intake and pulse wave velocity, salt loading affected vascular wall function regardless of blood pressure [40]. Collectively, renal fibrosis, inflammation, oxidative stress and arterial stiffness may all contribute to deterioration of renal function.

The risk of the lowest quartile of measured 24-h urinary Na excretion (<104.2 mEq/day) was not significantly higher than that of the second quartile of urinary Na excretion in this study. One study showed a significant association between low urinary Na excretion and incidence of ESRD in Type 1 DM [41]. Salt reduction contributed to increased RAS activity, increased sympathetic activity and increased insulin resistance. All of these changes are also risk factors of diabetic complications [42–45]. In the general population, a U-shaped association was identified

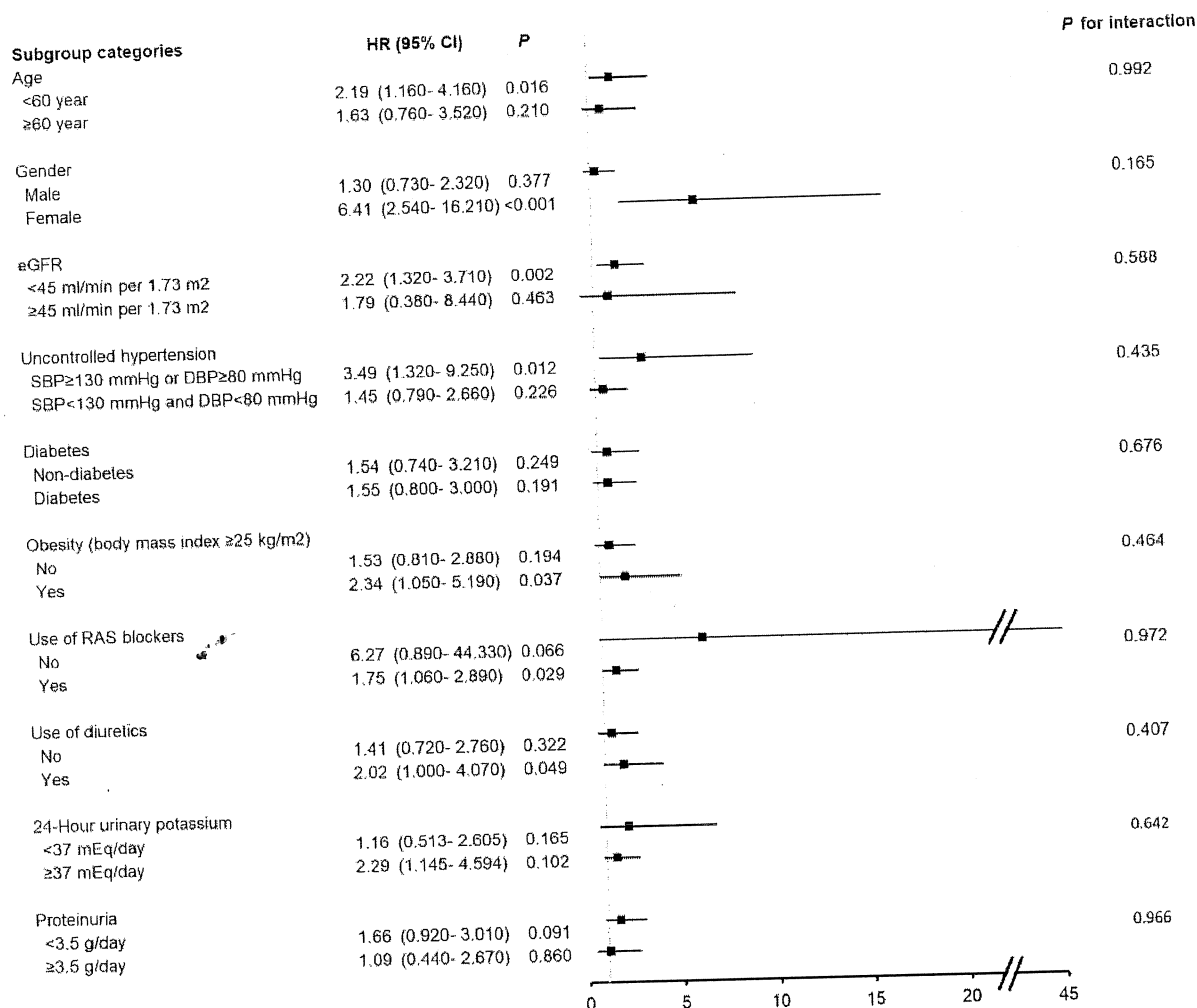


FIGURE 2: Subgroup analysis for the association of measured 24-h urinary sodium excretion with CKD progression. CI, confidence interval.

between daily salt intake and CKD development, which was defined as either eGFR <60 mL/min/1.73 m<sup>2</sup> or as development of proteinuria only when HTN was present [22]. These results also demonstrated an increased risk of poor renal outcome from very low salt intake. However, these data were limited to subjects with Type 1 DM or HTN. Therefore, these results might differ from those of the entire CKD population.

The increased risk of poor renal outcome from high salt intake was most pronounced in patients <60 years of age. The association between high salt intake and risk of poor renal outcome increased in subjects with HTN <60 years [22]. The activity of RAS was higher in young adults than it was in older people [46]. High RAS activity promoted vasoconstriction, cell proliferation and sympathetic activity [47], all of which could contribute to CKD progression.

In this study, urinary Na excretion was particularly associated with increased risk of renal outcome in women. Because of the differential effects of estrogen and testosterone on RAS, there may be sex differences in blood pressure [48]. Compared with estrogen, testosterone has a greater effect on angiotensin-converting enzyme (ACE) activity [49]. Because androgen deficiency develops in older men, post-andropausal men have low

serum aminopeptidase A (APA) and ACE activities. Both APA and ACE are components of RAS. Inhibition of these enzyme could play a role as antihypertensive drugs. In our data, >60% of patients were post-andropausal men or post-menopausal women (aged ≥55 years). Post-menopausal women experience greater changes in blood pressure than do post-andropausal men [49, 50]. Therefore, the risk of renal dysfunction may be higher in the female group than in the male group. This was also observed in the general population. High salt intake was strongly associated with risk of CKD development in women ≥60 years old. CKD development was defined as eGFR <60 mL/min/1.73 m<sup>2</sup> or development of proteinuria [22]. Based on these data, we can infer why the risk of CKD progression was pronounced in the female subgroup compared with the male subgroup.

The strengths of this study include a large, homogeneous population. Our study included variable etiologies of CKD with eGFR <60 mL/min/1.73 m<sup>2</sup>. Because information regarding measured 24-h urinary Na excretion was available for most subjects, it was possible to analyze the renal outcomes from a relatively large CKD population with long-term follow-up. Our sensitivity analysis using spot urine samples supported the primary analysis. This was the first Asian study to show a

association between high salt diet and CKD progression in CKD patients. Regardless, this study also has several limitations. It was an observational study of Korean CKD patients. The nutritional status evaluation such as food diary or food frequency questionnaire was not performed. In addition, dietary salt intake was based on a single measurement of 24-h urinary Na excretion at baseline. However, in the sensitivity analysis (that used estimated 24-h urinary Na excretion from spot urine sodium), the highest salt intake was also associated with risk of composite renal outcome.

In conclusion, high salt intake is associated with increased risk of CKD progression in CKD patients. In particular, risk was most pronounced in patients <60 years old or in women. Our findings suggest that urinary Na excretion is a predictor of CKD progression.

## SUPPLEMENTARY DATA

Supplementary data are available at [ndt](http://ndt.oxfordjournals.org/) online.

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## AUTHORS' CONTRIBUTIONS

The specific contribution of each author is as follows. M.K. and K.-H.O. designed the study. M.K. analyzed and interpreted the results and drafted the manuscript. E.K., H.R., S.K.P., Y.Y.H. and Y.H. analyzed and interpreted the data. J.K. advised and assisted in the statistical analysis. E.K., H.R., S.A.S. and S.W.K. reviewed and edited the manuscript. T.-H.Y., S.S.H. and C.A. conceived the study and assisted in the analyses. K.-H.O. conceived the study, analyzed the results, interpreted the data and reviewed the manuscript. All of the authors read and approved the final manuscript.

## CONFLICT OF INTEREST STATEMENT

None declared.

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