

ASSOCIATION BETWEEN QUESTIONNAIRE-ESTIMATED WATER INTAKE AND URINARY BIOMARKERS IN OLDER JAPANESE ADULTS: THE KOBE STUDY

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ABSTRACT – Objective: Accurate estimation of habitual water intake is crucial for epidemiological studies of water balance among older adults; however, reliable assessment methods for large-scale research remain limited. This study aimed to investigate the association between habitual water intake, as estimated by a “simplified lifestyle questionnaire for predicting habitual water intake” (SQW), and urinary biomarkers related to hydration and water balance in community-dwelling older adults.

Materials and Methods: A cross-sectional analysis was conducted on 268 participants enrolled in the 2022–2023 KOBE Study NEXT survey. Habitual total water intake and source-specific water intake were estimated using the SQW.

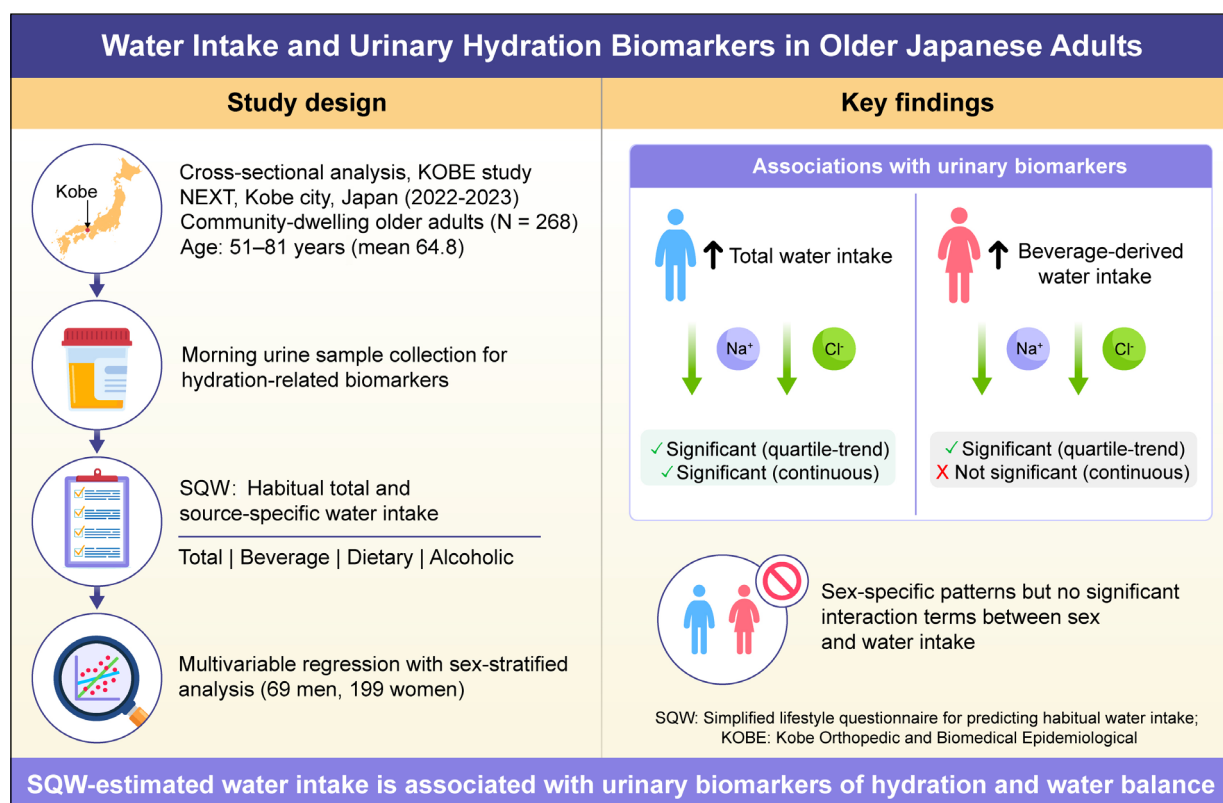
Early-morning spot urine samples collected after an overnight fast were used to measure urinary osmolality and electrolyte (sodium, potassium, and chloride) concentrations. The association between estimated water intake (analyzed as a continuous variable and by quartiles) and urinary biomarkers was examined using multivariable linear regression models after adjusting for age, sex, body mass index, smoking status, and alcohol consumption. Analyses were performed separately for men and women, and the sex–intake interaction term was tested.

Results: In men, higher total water intake was significantly associated with lower urinary sodium and chloride concentrations, but not with urinary osmolality. In women, higher beverage-derived water intake was associated with lower urinary osmolality and lower urinary sodium and chloride concentrations in quartile-based trend analyses, whereas continuous analyses showed similar but non-significant trends.

Dietary water intake and alcoholic beverage-derived water intake showed no significant association with urinary biomarkers in either sex. The sex–intake interaction term was not statistically significant.

Conclusions: Water intake estimated by the SQW was associated with urinary biomarkers related to hydration and water balance in older Japanese adults, with patterns varying according to water-intake source. These findings suggest that the SQW may serve as a practical tool for assessing habitual water intake in epidemiological and public health settings. Future longitudinal studies should investigate causality and clinical relevance.

KEYWORDS: Water intake assessment, Machine learning prediction, Urinary osmolality



Graphical Abstract. SQW-estimated water intake was associated with urinary biomarkers related to hydration and water balance in older Japanese adults.

INTRODUCTION

Water constitutes approximately 60% of body weight in adults, making it the largest component of the human body¹. Water is essential for life and plays a central role in diverse physiological functions beyond being a mere solvent, including thermoregulation, digestion, nutrient absorption and transport, waste excretion, and cellular homeostasis maintenance^{2,3}. Thus, maintaining habitual water intake is fundamental to homeostasis, and water deficiency or excess directly influences health status.

Cumulative clinical and epidemiological findings have highlighted the health risks associated with insufficient water intake. Chronic dehydration not only increases the risk of developing urolithiasis, diminished renal function, hypertension, and cardiovascular disease but is also linked to metabolic abnormalities associated with hyperglycemia^{4–6}. Furthermore, recent research has demonstrated its impact on physical diseases and brain function. Even mild dehydration is associated with cognitive decline, reduced attention and concentration, mood disturbances, increased headache, and fatigue^{7–10}, underscoring the importance of adequate hydration for optimizing both physical and mental performance.

Nonetheless, establishing accurate and convenient methods for measuring water intake in nutritional assessment has long been challenging. Conventional standard methods, such as the use of detailed weighed dietary records or a food frequency questionnaire, impose substantial burden on participants by requiring meticulous recording of dietary content¹¹. Additionally, for analysts, coding and analyzing vast amounts of data require considerable effort and time, limiting their applicability to large-scale population studies and routine health management¹².

To address these challenges, we developed a “simplified lifestyle questionnaire for predicting habitual water intake (SQW)” in our previous study¹³. The SQW utilizes machine learning (ML) algorithms to predict habitual water intake using 10–14 questions regarding an individual’s lifestyle. This model successfully combined carefully selected questions (e.g., those pertaining to meal frequency, meal size, and beverage preferences) from over 300 candidates, achieving high predictive accuracy and reducing the burden on participants. However, the verification of its validity in previous study¹³ primarily focused on correlations with water intake calculated from dietary records, and the extent to which SQW predictions are associated with urinary biomarkers related to hydration and water balance remains unclear.

Accordingly, the present study aimed (1) to investigate whether water intake estimated by the SQW is associated with urinary biomarkers related to hydration and water balance in older Japanese adults and (2) to provide construct-validity evidence by examining expected associations between SQW-estimated water intake and urinary biomarkers.

MATERIALS AND METHODS

Study design and participants

This cross-sectional study included participants from the Kobe Orthopedic and Biomedical Epidemiological (KOBÉ) study^{14–18}, a population-based cohort study that investigated the association between lifestyle factors and health among community-dwelling residents in Kobe City, Japan. The baseline survey of the KOBÉ study was conducted from 2010 to 2011. Participants were recruited *via* public announcements and open calls from residents aged 40–74 years who were subjectively healthy at the time of recruitment. The eligibility criteria were as follows: (1) having no history of major diseases (e.g., cancer, stroke, and coronary artery disease); (2) not receiving treatment for hypertension, diabetes mellitus, or dyslipidemia; and (3) being subjectively healthy.

The present analysis used data from the KOBÉ Study NEXT survey, an additional follow-up survey conducted with the KOBÉ study participants from 2022 to 2023. Among the participants of the KOBÉ Study NEXT survey, 268 individuals with available urinary data (urinary osmolality) were included in the present analysis to examine the association between fluid intake and urinary indicators (Figure 1).

Ethical considerations

This study was conducted in accordance with the Ethical Guidelines for Medical Research Involving Human Subjects and was approved by the Clinical Research Review Committee of Keio University School of Medicine and Hospital (protocol numbers: 20211116, approved on 24/12/2021,

and 20241072, approved on 30/07/2024). For the analyses, research information was published on a website, and consent was obtained from the research participants *via* an opt-out system.

Assessment of water intake and hydration-related biomarkers

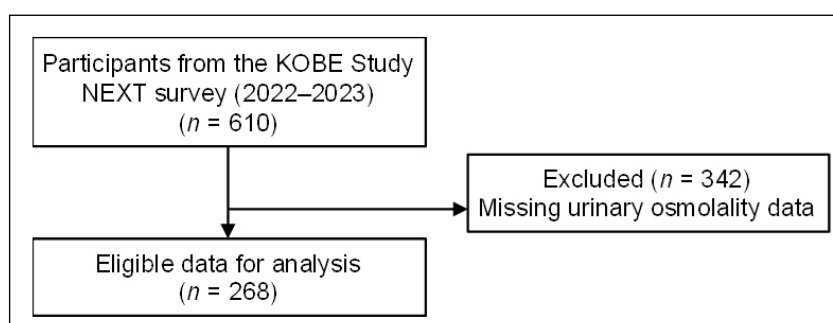
Water intake was estimated using the SQW¹³, a self-administered questionnaire that assesses habitual water intake using ML algorithms based on lifestyle-related questions. Total water intake was defined as the sum of water obtained from beverages, foods, and alcoholic beverages. Beverage-derived water intake referred to water obtained from non-alcoholic beverages, dietary water intake referred to water obtained from foods, and alcoholic beverage-derived water intake referred to water obtained from alcoholic beverages. In the present study, water intake estimated by the SQW was used for analysis. Early-morning spot urine samples were collected after an overnight fast, and urinary osmolality and electrolytes (sodium, potassium, chloride, and creatinine) were measured as urinary biomarkers related to hydration and water balance. All measurements were performed by SRL, Inc. (Tokyo, Japan). Height and body weight were measured during health checkups, and body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). Lifestyle-related factors, such as smoking status were assessed using a separate self-administered questionnaire.

Statistical analysis

The association between water intake and urinary osmolality and electrolyte concentrations was examined in 268 participants with complete urinary osmolality and electrolyte data. Analyses were conducted using complete-case data, and no missing values were found for variables included in the regression models.

Water intake was treated as a continuous variable. Multivariable linear regression models were

Figure 1. Flow diagram illustrating the selection of participants from the 2022–2023 KOBÉ Study NEXT survey. Participants with available urinary osmolality and electrolyte data were included in the final analysis ($n = 268$).



fitted separately for men and women to examine the associations between SQW-estimated water intake and urinary biomarkers. Models were adjusted for age (continuous), BMI (continuous), smoking status (never vs. ever), and alcohol consumption (g/day, continuous).

The urinary biomarkers included urinary sodium, potassium, chloride, osmolality, and creatinine. Regression coefficients (β) were estimated using water intake variables expressed as raw values (mL/day). For interpretability, regression coefficients and 95% confidence intervals were additionally presented per 100 mL/day increase in water intake.

Water intake was also categorized into quartiles (Q1–Q4), and adjusted mean values were estimated. Tests for linear trends were conducted by modeling quartile categories as ordinal variables. The false discovery rate (FDR) was controlled using the Benjamini–Hochberg procedure across the five urinary biomarkers within each sex- and exposure-specific family of analyses. Statistical significance was defined as a two-sided p -value <0.05 and an FDR-adjusted q -value <0.05 .

Model assumptions were tested by examining the residual plots to assess linearity and homoscedasticity. Multicollinearity was evaluated using variance inflation factors. Inspection of the distributions and residuals did not reveal departures likely to materially affect the estimates; the biomarkers were therefore analyzed on their original scale, and the princi-

pal findings were consistent when robust standard errors were considered. All statistical analyses were performed using R software version 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Participant characteristics

The 268 participants comprised 69 men [mean (SD) age, 65.6 (6.8) years; range, 53–81] and 199 women [64.5 (6.9) years; range, 51–77], with an overall mean age of 64.8 (6.9) years; all participants were older adults. The basic characteristics of the participants, stratified by total water intake quartiles (Q1–Q4), are summarized in Table I. BMI and smoking prevalence did not significantly differ among quartiles in either men or women. Among women, those with the highest total water intake tended to be significantly older.

Beverage- and food-derived water intake increased across total water intake quartiles, with higher values observed in the fourth quartile. In men, alcoholic beverage-derived water intake did not show a monotonic increase with the total water intake quartiles; it exhibited a nonlinear distribution, being low in the second and third quartiles and high in the fourth quartile. In women, alcoholic beverage-derived water intake tended to decrease as total water intake increased.

Table I. Participant characteristics stratified by the quartiles of total water intake.

Variable	Men					Women				
	Q1	Q2	Q3	Q4	$p_{\text{for_trend}}$	Q1	Q2	Q3	Q4	$p_{\text{for_trend}}$
n	18	17	17	17		50	50	50	49	
Age, years	65.7 $\pm$ 8.0	68.0 $\pm$ 5.9	64.9 $\pm$ 6.6	63.7 $\pm$ 6.5	0.223	62.1 $\pm$ 6.7	63.8 $\pm$ 7.0	66.0 $\pm$ 6.5	66.3 $\pm$ 6.8	<0.001
BMI, kg/m ²	23.5 $\pm$ 2.2	23.7 $\pm$ 3.0	23.0 $\pm$ 2.3	24.6 $\pm$ 3.6	0.376	20.4 $\pm$ 2.9	21.4 $\pm$ 3.5	20.6 $\pm$ 2.7	20.6 $\pm$ 2.9	0.926
Current smoker, %	12 (66.7%)	11 (64.7%)	12 (70.6%)	9 (52.9%)	0.499	7 (14.0%)	3 (6.0%)	3 (6.0%)	3 (6.1%)	0.175
Alcohol intake, g/day	16.6 (8.4, 43.2)	0.0 (0.0, 27.9)	4.3 (0.0, 28.1)	11.5 (0.0, 36.0)	0.497	0.0 (0.0, 8.6)	0.0 (0.0, 8.0)	0.0 (0.0, 1.4)	0.0 (0.0, 0.0)	0.103
Total water intake, mL/day	2,448.6 $\pm$ 173.6	2,878.7 $\pm$ 102.3	3,221.7 $\pm$ 94.3	3,799.8 $\pm$ 390.7	<0.001	2,375.3 $\pm$ 212.1	2,755.5 $\pm$ 73.6	3,060.5 $\pm$ 96.1	3,567.5 $\pm$ 221.6	<0.001
Beverage-derived water, mL/day	1,445.1 $\pm$ 250.7	1,592.4 $\pm$ 284.7	1,693.3 $\pm$ 243.2	1,900.3 $\pm$ 348.1	<0.001	1,360.0 $\pm$ 265.2	1,636.6 $\pm$ 273.5	1,829.7 $\pm$ 239.2	1,930.2 $\pm$ 196.5	<0.001
Dietary-derived water, mL/day	1,076.7 $\pm$ 88.6	1,131.1 $\pm$ 151.1	1,299.7 $\pm$ 196.5	1,315.0 $\pm$ 169.9	<0.001	1,035.4 $\pm$ 151.1	1,110.2 $\pm$ 170.1	1,140.5 $\pm$ 184.5	1,234.5 $\pm$ 152.8	<0.001
Alcohol-derived water, mL/day	430.7 $\pm$ 195.2	172.1 $\pm$ 216.1	170.5 $\pm$ 200.8	311.8 $\pm$ 286.0	0.158	148.1 $\pm$ 205.9	140.7 $\pm$ 180.2	46.0 $\pm$ 107.4	66.7 $\pm$ 131.6	0.001
Urinary osmolality, mOsm/kg	758.8 $\pm$ 164.9	634.3 $\pm$ 236.0	613.4 $\pm$ 233.6	648.8 $\pm$ 150.0	0.100	555.5 $\pm$ 243.8	562.3 $\pm$ 220.8	539.6 $\pm$ 171.5	488.7 $\pm$ 207.3	0.100

Values are presented as mean $\pm$ SD for continuous variables and as percentages for categorical variables. The participants were categorized into quartiles (Q1–Q4) based on total water intake separately for men and women. The p -value for trend was calculated using a linear regression model, with quartile categories treated as ordinal variables.

Relationship between total water intake and urinary indicators

The association between total water intake and urinary indicators was analyzed separately for men and women. When total water intake was analyzed as a continuous variable, higher total water intake was significantly associated with lower urinary sodium and chloride concentrations in men (Figure 2A–B). Specifically, each 100 mL/day increase in total water intake was associated with a 3.01 mmol/L decrease in urinary sodium concentration (95% CI: –5.13 to –0.88; $q = 0.0155$) and a 3.69 mmol/L decrease in urinary chloride concentration (95% CI: –6.18 to –1.20; $q = 0.0155$). In contrast, urinary osmolality showed an inverse but non-significant association (Figure 2C; β per 100 mL/day = –7.59 mOsm/kg, 95% CI: –17.00 to 1.81; $q = 0.1859$). No significant association between total water intake

and urinary biomarkers was observed in women after FDR correction (Figure 2A–C). Urinary potassium and creatinine concentrations were not significantly associated with total water intake in either sex. Regression coefficients, 95% confidence intervals, nominal p -values, and FDR-adjusted q -values for the continuous analyses are presented in [Supplementary Table I](#).

Trend analysis classifying total water intake into quartiles revealed a trend consistent with the continuous variable analysis. In men, urinary sodium and chloride concentrations showed a significant decreasing trend across quartiles (Figure 2D–E). In women, no significant linear trend was observed for urinary osmolality and urinary sodium and chloride concentrations across the total water intake quartiles (Figure 2D–F). Neither urinary potassium nor creatinine levels exhibited significant changes in either analysis.

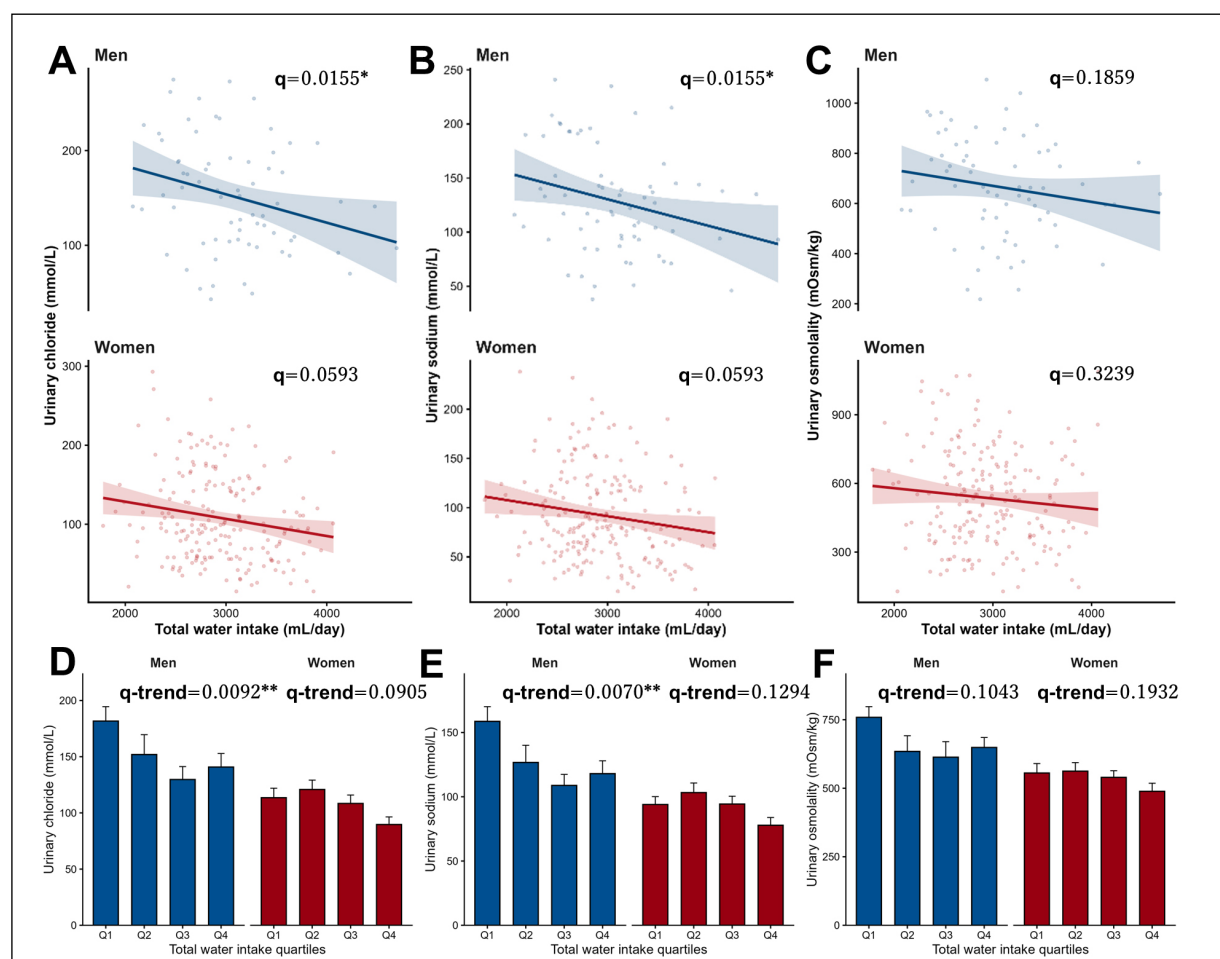


Figure 2. Association between total water intake and urinary biomarkers. Data from 268 participants (69 men and 199 women) were analyzed. **A–C**, Sex-stratified scatter plots showing the relationship between total water intake (mL/d) and urinary biomarkers (chloride, sodium, and osmolality). Regression lines and 95% confidence intervals (CIs) were derived from linear regression models adjusted for age, BMI, smoking status, and alcohol consumption (g/day). **D–F**, Adjusted mean values of urinary biomarkers across total water intake quartiles (Q1–Q4) in men (blue) and women (red). Error bars represent SEM. Statistical significance was determined using Benjamini–Hochberg-adjusted q -values to account for multiple comparisons. Linear trends (q -trends) were examined by treating quartile categories as ordinal variables. * $q < 0.05$, ** $q < 0.01$.

Association between beverage-derived water intake and urinary indicators

The association between beverage-derived water intake and urinary indicators was analyzed separately for men and women. When beverage-derived water intake was analyzed as a continuous variable, urinary osmolality (Figure 3C) and urinary sodium and chloride concentrations (Figure 3A–B) showed inverse associations with increasing beverage-derived water intake in women; however, these associations did not remain statistically significant after FDR correction. In contrast, no significant association between beverage-derived water intake and urinary biomarkers was observed in men (Figure 3A–C). Urinary potassium and creatinine concentrations were not significantly associated with beverage-derived water intake in either sex.

Trend analysis classifying beverage-derived water intake into quartiles indicated that urinary osmolality and urinary sodium and chloride concentrations decreased significantly in women as quartile levels increased (Figure 3D–F). In men, no significant linear trend was observed for these urinary indicators across beverage-derived water intake quartiles (Figure 3D–F). Urinary potassium and creatinine concentrations were not significantly associated with beverage-derived water intake in either men or women.

Association between dietary or alcoholic beverage-derived water intake and urinary indicators

Trend analyses using multivariable-adjusted regression were conducted to examine the association between dietary or alcoholic beverage-derived water intake and urinary indicators.

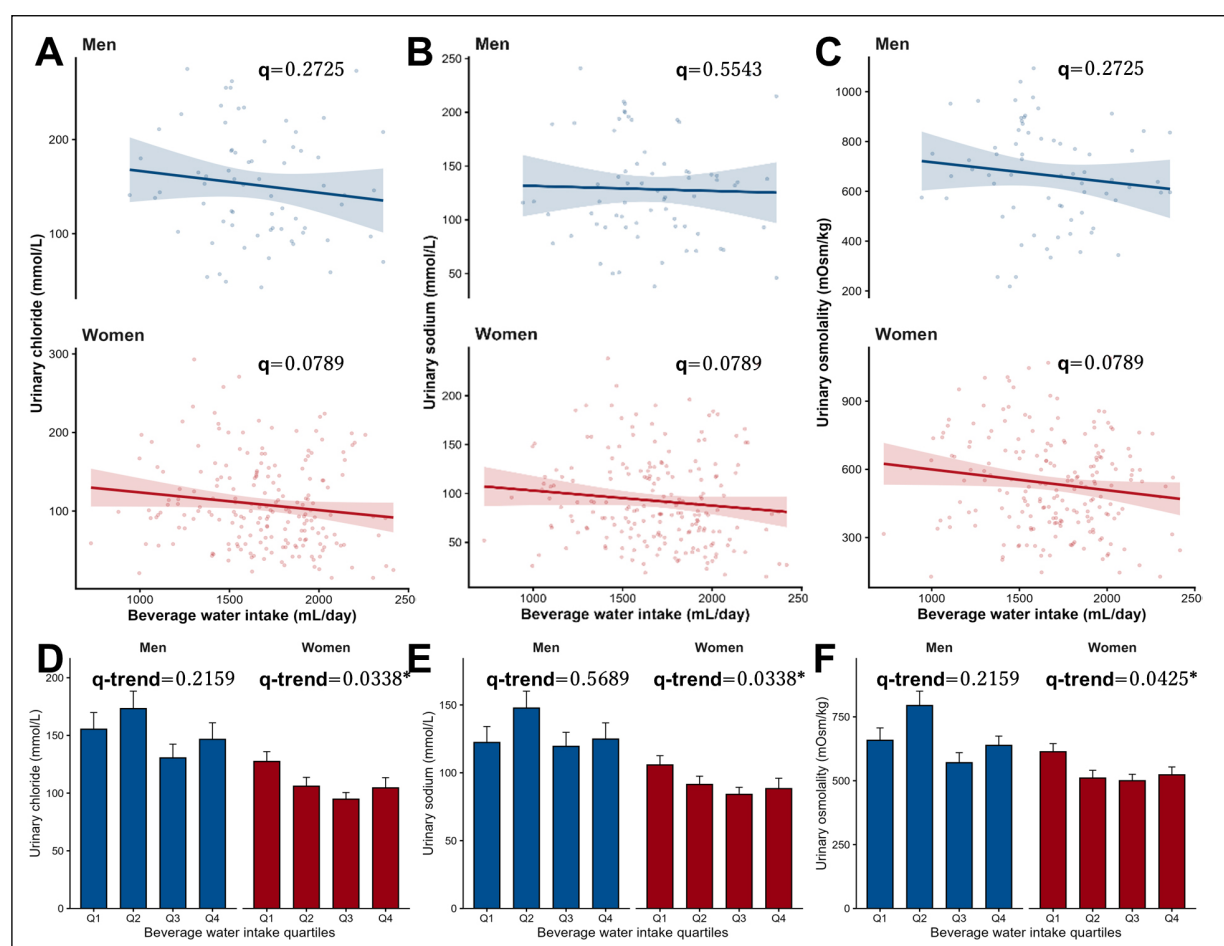


Figure 3. Associations between beverage-derived water intake and urinary biomarkers. Data from 268 participants (69 men and 199 women) were analyzed. **A–C**, Sex-stratified scatter plots showing the relationship between beverage-derived water intake (mL/d) and urinary biomarkers (chloride, sodium, and osmolality). Regression lines and 95% confidence intervals (CIs) were derived from linear regression models adjusted for age, BMI, smoking status, and alcohol consumption (g/day). **D–F**, Adjusted mean values of urinary biomarkers across quartiles (Q1–Q4) of beverage-derived water intake in men (blue) and women (red). Error bars represent SEM. Statistical significance was determined using Benjamini–Hochberg-adjusted q -values to account for multiple comparisons. Linear trends (q -trends) were examined by treating quartile categories as ordinal variables. $^*q < 0.05$.

Regarding dietary water intake, no significant trends were observed for any urinary indicators (urinary osmolality, sodium, potassium, chloride, or creatinine) in either men or women (Table II). Similarly, regarding alcoholic beverage-derived water intake, no significant trends were identified for any urinary indicators in either men or women (Table II).

In all analyses, the interaction term for sex was not significant in the relationship between water intake and urinary indicators (Table II).

DISCUSSION

Sex differences in the association between water intake and urinary indicators

To the best of our knowledge, the present study is among the first investigations to evaluate whether water intake estimated using an ML-based prediction model (i.e., the SQW) is associated with

urinary biomarkers related to hydration and water balance in community-dwelling older adults.

Both total water intake and beverage-derived water intake were associated with urinary indicators, with different patterns observed in sex-stratified analyses; however, the interaction term was not statistically significant. Conversely, dietary water intake and alcoholic beverage-derived water intake showed no clear association with urinary indicators.

The findings of this study extend previous work on the SQW model, which was originally developed using dietary records, by demonstrating its association with urinary biomarkers related to hydration and water balance. These findings suggest that different water sources may be differentially reflected in urinary biomarker profiles, although this interpretation should be considered exploratory.

In men, increased total water intake was associated with decreased urinary sodium and chloride concentrations and a nonsignificant downward trend in urinary osmolality. In women, beverage-derived water intake was associated with urinary osmolality

Table II. Multivariable-adjusted quartile trend analyses for the associations between water intake and urinary biomarkers.

Outcome (urinary biomarker)	P-trend (Men)	q-trend (Men)	P-trend (Women)	q-trend (Women)	P_inter	q_inter
Total water intake						
Urinary osmolality	0.0626	0.1043	0.1159	0.1932	0.4971	0.6539
Urinary sodium	0.0014	0.0070	0.0518	0.1294	0.2019	0.6469
Urinary potassium	0.8315	0.8315	0.2486	0.2772	0.6539	0.6539
Urinary chloride	0.0037	0.0092	0.0181	0.0905	0.2588	0.6469
Urinary creatinine	0.3011	0.3763	0.2772	0.2772	0.5302	0.6539
Beverage-derived water intake						
Urinary osmolality	0.1686	0.2159	0.0255	0.0425	0.9316	0.9316
Urinary sodium	0.5689	0.5689	0.0135	0.0338	0.8295	0.9316
Urinary potassium	0.1203	0.2159	0.1070	0.1338	0.8164	0.9316
Urinary chloride	0.1727	0.2159	0.0088	0.0338	0.7139	0.9316
Urinary creatinine	0.1238	0.2159	0.1770	0.1770	0.5228	0.9316
Dietary-derived water intake						
Urinary osmolality	0.5233	0.6158	0.4620	0.5775	0.8895	0.9249
Urinary sodium	0.0566	0.1616	0.0853	0.2665	0.2848	0.7121
Urinary potassium	0.4630	0.6158	0.3800	0.5775	0.9249	0.9249
Urinary chloride	0.0647	0.1616	0.1066	0.2665	0.2617	0.7121
Urinary creatinine	0.6158	0.6158	0.5840	0.5840	0.8989	0.9249
Alcohol-derived water intake						
Urinary osmolality	0.8175	0.8523	0.6778	0.6872	0.8279	0.8941
Urinary sodium	0.8523	0.8523	0.5751	0.6872	0.8941	0.8941
Urinary potassium	0.6534	0.8523	0.6872	0.6872	0.5448	0.8941
Urinary chloride	0.5574	0.8523	0.2160	0.6872	0.5002	0.8941
Urinary creatinine	0.6281	0.8523	0.4104	0.6872	0.8661	0.8941

The association between water intake from different sources and five urinary biomarkers was explored through linear regression analyses. The participants were categorized into quartiles (Q1–Q4) according to water intake from each source.

The *p*-value was calculated using a multivariable model adjusted for age, BMI, smoking status, and alcohol intake (g/day), with quartile categories treated as ordinal variables.

The *q*-trend was calculated using the Benjamini–Hochberg false discovery rate (FDR) procedure to account for multiple tests across five biomarkers, with analyses conducted separately for each sex and water intake source.

An interaction term between sex and water intake quartile was included in a separate model using total population (*p*_inter and *q*_inter) to evaluate potential sex differences.

and urinary sodium and chloride concentrations in quartile-based analyses, suggesting that the impact of different water-intake sources on hydration-related urinary biomarkers may differ by sex; however, these findings should be interpreted cautiously because the formal sex–intake interaction term was not statistically significant.

Urinary osmolality and electrolytes are urinary biomarkers related to body water balance^{19,20} and are regulated by the renal mechanisms of urine concentration and dilution in response to changes in water intake. Previous observational and interventional studies^{2,21} reported a decrease in urinary osmolality as water intake increased.

In the present study, the association of total water intake and beverage-derived water intake with urinary electrolytes aligns with these physiological findings. The associations observed for urinary sodium and chloride concentrations should be interpreted cautiously because these biomarkers are influenced not only by water intake but also by dietary sodium intake and renal sodium handling. As dietary salt intake was not directly assessed in the present study, residual confounding cannot be excluded. However, not all urinary indicators showed a uniformly significant association, implying that multiple factors beyond water intake alone—such as renal function, hormonal regulation, body composition, and temporal distribution of water intake—influence urinary indicators²².

Sex differences in the relationship between water intake and urinary osmolality or electrolytes have been previously reported, with differences in muscle mass, body water content, and variations in renal function regulation by sex hormones having been identified as possible underlying factors^{23,24}. Men generally have greater fat-free mass and higher water storage capacity than women, potentially leading to different responses among urinary indicators to the same degree of change in water intake²⁵. In this study, total water intake correlated with urinary sodium and chloride levels in men, whereas beverage-derived water intake showed a clearer association with urinary osmolality and electrolytes in women. These results are consistent with those of previous studies²¹ that suggested sex differences in the association between water intake and urinary indicators; however, because no statistically significant interaction was observed, the present findings should be considered exploratory rather than evidence of established effect modification by sex.

Sex differences in beverage consumption behaviors and temporal water intake patterns may exist²², and such behavioral factors may influence how these factors are reflected in spot urine indicators. However, in this study, the interaction with sex was not statistically significant, and the

observed sex differences should be interpreted with caution as hypothesis-generating findings.

In women, the inverse associations of beverage-derived water intake with urinary osmolality, sodium, and chloride did not reach statistical significance in the continuous models after FDR correction, whereas the corresponding quartile-based trend analyses were significant. This pattern is compatible with a non-linear dose–response relationship, in which differences are driven mainly by contrasts between the extreme quartiles, and with the limited power of continuous models to detect associations of modest magnitude. The two sets of analyses should therefore be interpreted together rather than as contradictory findings.

Water intake by source

Analysis by water-intake source revealed that beverage-derived water intake was associated with urinary osmolality and electrolyte concentrations in selected analyses, whereas dietary water intake and alcoholic beverage-derived water intake were not. Although food-derived water accounts for a relatively large proportion of total water intake among Japanese individuals²⁶, the lack of association between dietary water intake and urinary indicators in this study may suggest that beverage-derived water intake is more strongly reflected in urinary biomarker profiles than dietary water intake. Furthermore, the characteristics of Japanese cuisine (i.e., high water and salt contents) may have led to a dilution effect that counterbalances the solute load^{27,28}.

Regarding alcoholic beverage-derived water intake, alcohol consumption causes transient diuresis, reducing its contribution to fluid retention²⁹. The lack of association between urinary indicators in this study is consistent with these physiological characteristics.

Epidemiological study in an older adult population

The results of this study indicated that water intake estimated by a simple lifestyle questionnaire was associated with selected urinary biomarkers related to hydration and water balance. This presents a practical option for water intake assessment in older adults, a population, on which research remains limited. Considering that many previous studies^{26,30,31} were based on short-term interventions or other small-scale studies involving younger individuals, the present study provides new evidence for assessing water intake in large-scale epidemiological studies and public health settings. In situations in which de-

tailed dietary records are difficult to obtain, combining a simple questionnaire, such as the SQW, with urinary biomarkers may be useful for characterizing water-intake patterns and hydration-related urinary biomarker profiles at the population level.

Strengths and limitations

The strengths of this study lie in its foundation in a large community-based cohort and in its examination combining water intake estimated by a simple questionnaire with urinary biomarkers related to hydration and water balance, including urinary osmolality and electrolytes. Detailed analyses according to sex and age were also key features.

However, this study had some limitations. First, this cross-sectional study could not directly examine causality. Nonetheless, the observed associations are consistent with established physiological mechanisms linking water intake to urinary concentration and dilution, suggesting that these findings are biologically plausible. Second, water intake was estimated using a questionnaire, and measurement errors could not be completely eliminated. Nevertheless, the SQW model was developed and validated using dietary records in previous study¹³, which may help reduce any systematic misclassification of water intake. Third, although urine samples were collected as early-morning spot urine samples after an overnight fast, spot urine biomarkers may still be influenced by day-to-day behavioral and environmental factors, including season and ambient temperature, which were not accounted for in the present analysis, potentially creating a temporal mismatch with habitual water intake estimated by the questionnaire. Therefore, the use of spot urine samples may have introduced additional measurement variability. Fourth, residual confounding factors could not be ruled out. In particular, dietary sodium intake was not assessed and may have influenced the observed associations with urinary sodium and chloride concentrations. Fifth, urinary biomarker measurements were available only for those participants who provided a urine sample; the analytical sample may therefore not be fully representative of the source population, and the possibility of selection bias, with consequent limits on generalizability, cannot be excluded.

CONCLUSIONS

Water intake estimated by the SQW was associated with urinary osmolality and electrolytes that are related to hydration and water balance in old-

er adults in Japan. These findings suggest that a simple lifestyle questionnaire-based estimation of water intake may reflect hydration-related urinary biomarker profiles at the population level. These associations appeared to differ according to water-intake source and in exploratory sex-stratified analyses, although formal interaction testing did not support statistically significant effect modification by sex.

Importantly, the present findings should not be interpreted as validating the SQW as a diagnostic tool for hydration status. Rather, the findings provide construct-validity evidence that SQW-estimated water intake is associated with urinary biomarkers related to hydration and water balance in community-dwelling older adults. Further validation against reference standards, such as serum or plasma osmolality or 24-hour urine measures, would be required before the SQW could be applied to hydration-related screening.

CONFLICT OF INTEREST

Jl, KM, YN, HW and NM are employees of Suntory Global Innovation Center, Ltd. The remaining authors declare that they have no conflict of interest to disclose.

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AUTHORS' CONTRIBUTIONS

Junki Ikeguchi: Data Curation, Formal Analysis, Writing – Original Draft Preparation, Writing – Review & Editing.
Aya Hirata: Conceptualization, Data Curation, Writing – Review & Editing.
Keiko Mizuma: Conceptualization.
Yumi Nakamura: Conceptualization, Writing – Review & Editing.
Hiroshi Watanabe: Conceptualization.
Norihito Murayama: Conceptualization.
Hiroaki Ueshima: Formal Analysis.
Hiroshi Tamura: Formal Analysis.
Tomonori Okamura: Conceptualization, Data Curation, Writing – Review & Editing.
All authors have read and approved the final manuscript.

DATA AVAILABILITY

The datasets analyzed during the current study are not publicly available because they contain sensitive participant information and are subject to institutional and ethical restrictions. Data may be available from the corresponding author upon reasonable request and with appropriate ethical approval.

AI DISCLOSURE

Artificial intelligence (AI) was used solely for English language editing and proofreading of the manuscript. AI was not used to generate scientific content, analyze data, interpret results, or prepare tables and figures.

ETHICS APPROVAL AND INFORMED CONSENT

This study was conducted in accordance with the Declaration of Helsinki and the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects. The study protocol was approved by the Clinical Research Review Committee of Keio University School of Medicine and Hospital (protocol numbers 20211116, approved 24/12/2021, and 20241072, approved 30/07/2024). Informed consent was obtained from all participants through an opt-out procedure, whereby research information was disclosed on a public website.

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