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Estimation of 24-Hour Urinary Sodium Excretion Using Spot Urine Sample in The Adult Population in Shandong, China

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Short Report

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Abstract

This study assessed the reliability of equations for estimating 24-hour urinary sodium excretion using first-time morning urine samples. In this study, a total of 2078 residents of Shandong Province in 2019 and 2024 were randomised, and three equations for estimating 24-HUNa were fitted using morning urine samples and 24-hour urine samples from 1454 participants (46.6 ± 13.4 years old), and the three equations as well as equations developed by other researchers were were validated. In the validation group, estimated 24-HUNa was significantly correlated with measured 24-HUNa values. There was no significant difference between the estimated 24-HUNa and the measured 24-HUNa for the three equations fitted in this study, whereas there was a significant difference between the estimated 24-HUNa and the measured 24-HUNa values using Kawasaki and Tanaka et al. In the Bland-Altman analyses, the agreement between measured and estimated 24-HUNa values for the six equations was more than 2500 mg / 24 hours. All equations showed a tendency to underestimate or overestimate 24-HUNa between different levels of actual 24-HUNa values, hypertension status, and age groups. None of the equations tested in this study could estimate an individual's 24-HUNa from a single SU. The SMASH equation fitted in this study was superior to those of other researchers in assessing population-level 24-HUNa excretion in Shandong Province.

1. Introduction

Sodium is a core electrolyte, vital for maintaining physiological homeostasis in the human body. Research indicates that the average daily salt intake of Chinese residents exceeds the amount recommended by the WHO by more than double [1]. A diet with a high salt content has been demonstrated to increase the risk of cardiovascular disease, thus representing the primary dietary risk factor contributing to the loss of healthy life years among Chinese residents [2]. It is estimated that approximately 5 million people die each year due to excessive salt intake, which poses a significant threat to global public health [3]. An accurate assessment of sodium intake is a prerequisite for the formulation and optimisation of salt reduction policies. However, existing assessment methods have limitations.

The gold standard for assessing sodium intake is the 24-hour urinary sodium excretion, which reflects the metabolic end products of more than 90% of dietary sodium, [4, 5] however, the intricacy of the operation renders its application to large-scale population surveys challenging. In this regard, researchers have proposed an alternative method of estimating 24-hour urinary sodium excretion using spot urine samples (SU) combined with mathematical models, such as the Kawasaki, Tanaka, and INTERSALT equations. These methods offer the advantages of convenience and low cost, providing a potential tool for monitoring sodium intake in populations, particularly in countries such as China that are implementing national salt reduction strategies.

The applicability of point urine equations remains a subject of controversy in extant research. A substantial body of research has been conducted in the Chinese population, utilising various equations

to estimate sodium excretion. These studies have revealed notable variations in the estimation outcomes, with some equations demonstrating a tendency to systematically overestimate or underestimate the true values. In a study by Peng et al. involving 116 residents of Shanxi Province, China, the Kawasaki, Tanaka, and INTERSALT methods were found to underestimate 24-hour urinary sodium excretion, with the INTERSALT method showing the greatest bias and the Kawasaki method the least [6]. In a study of 141 residents of Jiangxi Province, China, Zhou et al. found that the misclassification rates of individuals using the Kawasaki, Tanaka, and INTERSALT methods all exceeded 60% [7]. This discrepancy may be attributable to population heterogeneity, for instance in dietary habits and renal function, or alternatively due to the utilisation of incomplete multidimensional data (e.g. physical measurements, urine creatinine) or limited sample sizes, which compromise the accuracy of the models. Predictions for populations in northern China with high salt intake, especially those in Shandong Province (with a daily per capita salt intake of 12.5 g), remain unclear [8,9].

Drawing upon the aforementioned background, this study employs large-scale population data from Shandong Province, China, to address two fundamental issues: firstly, to develop a 24-hour urinary sodium excretion fitting equation using spot urine sodium data; and secondly, to explore the differential effects across different demographic and clinical subgroups. The study's findings will provide empirical evidence to optimise sodium intake assessment methods, while concurrently establishing a scientific basis for the precise implementation of regional salt reduction policies and the monitoring of salt intake levels.

2. Experimental Section

2.1 Study Participants

In order to prevent and control hypertension and reduce dietary sodium intake, the Chinese Ministry of Health and the Shandong Provincial Government jointly launched the 'Shandong Province Ministry of Health Salt Reduction and Hypertension Prevention Action Plan' (SMASH) in 2011. The 24-hour urine sodium data from Shandong Province were obtained from the baseline survey of the SMASH study, which targeted residents aged 18 to 69 who had resided in the local area for more than six months. The data were collected using a four-stage stratified cluster random sampling method, with participants selected from 52 administrative villages/residents' committees, 52 towns/districts, and 20 counties/districts [10]. In order to ensure provincial representativeness of the study, design weight sampling and population structure adjustment were also conducted.

The data utilised in this study were obtained from the 2019 and 2024 SMASH follow-up surveys, which included relatively complete spot urine and 24-hour urine samples. The data set comprised a total of 3,016 individuals, of whom 2,445 completed a 24-hour urine collection. Following the exclusion of 367 invalid 24-hour urine samples, the final sample size was determined to be 2,078 individuals (see Figure S1). Prior to participating in the study, all participants provided informed consent. The present study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee for

Preventive Medicine of the Shandong Provincial Centre for Disease Control and Prevention (approval number 2016-7, approval date 29 April 2016).

2.2 Data collection

The participants were informed of the procedures for handling spot urine and 24-hour urine samples through both verbal and written instructions. Each participant was furnished with a urine collection cup and a test tube for the purpose of storing the SU sample. In the morning, participants were required to collect a clean midstream SU sample at home. Subsequently, participants were required to bring the SU sample to the designated survey site.

Participants are requested to commence 24-hour urine collection upon their arrival at the designated study site, ensuring that they voided their bladders. Each participant is provided with a plastic bottle with a lid for the collection of a 24-hour urine sample, which contains approximately 1.0 grams of boric acid. Participants are then required to collect all urine over the subsequent 24 hours, including the initial urination the following morning. On the second day, each participant is required to return to the designated study site at the stipulated time. The commencement and cessation times of the 24-hour urine collection are meticulously documented by a supervising healthcare professional. Following the completion of the urine collection, each participant is administered a questionnaire to evaluate the completeness of the collection.

The 24-hour urine samples obtained from each participant were meticulously mixed and the total volume was measured. A 20-ml urine sample was then aliquoted and frozen at -20°C. All urine samples were transported frozen to the ADICON Clinical Laboratory in Jinan, China, for analysis. The 24-hour urine sodium and potassium tests were performed using the ion-selective electrode method with the Olympus AU 680 automatic analyser (Beckman Coulter Co., Ltd., Tokyo, Japan). The urine creatinine test was performed using the enzyme method with the Olympus AU 640 analyser (Beckman Coulter Co., Ltd., Tokyo, Japan).

A range of other measurements were obtained by trained medical professionals, who employed standardised methods to ensure the accuracy of the results. These measurements included weight, height, and blood pressure. Participants were instructed to wear light indoor clothing and to remove their shoes prior to undergoing the height and weight measurements. The body mass index (BMI) was calculated using the following formula: weight (in kilograms) divided by height (in metres) squared. The measurement of blood pressure was conducted utilising a certified automatic device (HEM-7071, Omron Corporation, Dalian, China) at 5-minute intervals, with a total of three measurements being taken. The mean of these three measurements was documented. Hypertension was defined as systolic blood pressure (SBP) ≥ 140 mmHg and/or diastolic blood pressure (DBP) ≥ 90 mmHg.

The following criteria were used to determine exclusion from the study: Individuals exhibiting creatinine excretion levels that fall outside the established normal range. This study considers such individuals to have abnormal creatinine excretion levels, which do not meet the prerequisites of this study. In the

context of the analysis of spot urine sample data, individuals exhibiting spot urine creatinine concentrations that lay outside the specified range for males (3.45–22.90 mmol/L) and females (2.47–19.20 mmol/L) were excluded from the study. Similarly, in the analysis of 24-hour urine sample data, individuals demonstrating 24-hour urine creatinine excretion levels that lay outside the specified range for males (803–2001 mg) and females (599–1798 mg) were also excluded from the study.

2.3 Development of Equation

In the derivation process, assumptions similar to those employed in previous traditional studies were adopted [11, 12]. Initially, the 24-hour urinary creatinine excretion rate can be estimated through the use of physical indicators such as height, weight, and age. Secondly, the ratio of 24-hour urinary sodium to 24-hour urinary creatinine is proportional to the ratio of spot urinary sodium to spot urinary creatinine. It can thus be deduced that Predicted 24-hour Na excretion is proportional to (Spot urine Na/Spot urine Creatinine)*24-hour Creatinine excretion.

It is evident that, in order to derive 24-hour urinary sodium, it is first necessary to divide the total population into training and testing sets using a randomisation method. Thereafter, the fitting equation for 24-hour urinary creatinine excretion can be derived. Finally, the predicted values of 24-hour urinary creatinine excretion were used to replace the actual values, and the fitting equation for 24-hour urinary sodium excretion was derived.

During the fitting process for 24-hour urinary creatinine excretion, equations were established to predict 24-hour urinary creatinine excretion based on height, age, waist circumference, waist-to-hip ratio, and BMI for the training set population, stratified by gender. In the subsequent phase, the established prediction equations were validated and compared with traditional prediction equations in the test set. The findings demonstrated that, within the validation set, the predictive equation developed in this study exhibited the highest correlation coefficient ($r = 0.663$, $P < 0.001$), while the Kawasaki equation demonstrated a correlation coefficient of 0.467 ($P < 0.001$), and the Tanaka equation exhibited the lowest correlation coefficient of 0.184 ($P < 0.001$).

The 24-hour urine creatinine prediction equation developed in this study is as follows:

Estimate 24-hour urinary createin for male = $8.325\times\text{Weight} - 0.9854\times\text{Height} - 0.0003907\times\text{Age}^3 + 474.3\times\text{WHR} - 8.929\times\text{BMI} + 715.3$

Estimate 24-hour urinary createin for female = $9.670\times\text{Height} + 14.506\times\text{Age} - 0.180\times\text{Age}^2 - 8.757\times\text{WC} + 573.634\times\text{WHR} + 27.596\times\text{BMI} - 1273.214$

According to the second hypothesis of this study, predicted 24-hour sodium excretion is directly proportional to (Spot urine sodium/Spot urine creatinine) × 24-hour creatinine excretion. In this study, (Spot urine Na/Spot urine Creatinine) * 24-hour Creatinine excretion is denoted as XNa, where 24-hour Creatinine excretion is calculated using the 24-hour urine creatinine prediction equation fitted in this study. By fitting the actual values of XNa and 24-hour urine sodium excretion from morning random spot

urine samples, an equation was established to predict 24-hour urine sodium excretion using morning random spot urine samples.

In order to explore the possible linear trends, non-linear trends, and confounding effects of multiple factors between spot urine sodium and 24-hour urine sodium, this study selected Linear Equation, Power-law Equation, and multiple linear regression models for fitting in the training set. The fitting effects of the current three equations and the three traditional equations of Kawasaki, Tanaka, and INTERSALT were then verified in the validation set.

The final three different forms of the 24-hour urinary sodium excretion prediction equations are as follows:

Linear Equation:

Estimate 24-hour urinary sodium excretion = 0.07723*XNa + 2529

Power-law Equation:

Estimate 24-hour urinary sodium excretion = 101.11321*XNa^0.37715

SMASH Equation:

Estimate 24-hour sodium excretion = 820.7 + 26.42 * age − 0.2894 * age² − 882.5 * WHR + 50.3 * BMI + 0.1149 * XNa − 0.0000005296 * XNa² + 5.298 * SUNa − 34.68 * (SUNa/SUCr)

Among these, XNa = (SUNa/SUCr) × PrUCr, where SUNa is the concentration of sodium ions in morning spot urine (mmol/L) and SUCr is the concentration of creatinine in morning spot urine (mmol/L).

2.4 Statistical Analysis

A randomised grouping strategy was adopted in order to divide the entire sample into a training set and a test set, with the training set accounting for 70% and the test set accounting for 30%. The quantitative data was the subject of a descriptive statistical analysis, with the results expressed as mean ± standard deviation. Categorical variables were expressed as counts or percentages. The differences between the groups were analysed using either t-tests or analysis of variance (ANOVA).

The 24-hour urinary sodium prediction values for each equation in the test set population must be calculated. At the population level, a scatter plot should be created, showing the predicted and actual 24-hour urinary sodium values. The correlation coefficient r should then be calculated between the predicted and actual values. Finally, a paired samples t-test should be used to assess the difference between the actual and predicted 24-hour urinary sodium values. At the individual level, the Bland-Altman method is to be employed in order to evaluate the agreement between the actual and predicted 24-hour urinary sodium values. The discrepancy between the observed and anticipated values is determined by subtracting the former from the latter. A scatter plot should be plotted of the differences against the

actual 24-hour urinary sodium values, and the correlation coefficient r should be calculated. The percentage error can then be calculated using the following formula: 1.96 × (standard deviation of the difference between the actual and predicted 24-hour urinary sodium values) / (mean of the actual 24-hour urinary sodium values) × 100.

3. Results

The final study comprised 2,078 participants, of whom 70% (N = 1,454) constituted the training set (Derivation Cohorts) and 30% (N = 624) comprised the validation set (Validation Cohorts).

3.1 Baseline Characteristics

In the training set, the average age of participants was 46.6 ± 13.4 years, with 46.1% of participants being male, 70.1% not having hypertension, a 24-hour urinary sodium excretion of 3990 ± 1850 mg/24 hours, and a corresponding salt intake of approximately 11.3 ± 5.2 g/day. An investigation into the fundamental characteristics of the training set and the test set revealed no statistically significant disparities (see Table 1).

Table 1
Baseline Characteristics of the Derivation and Validation Cohort

Characteristics	Derivation (*N* = 1454)	Validation (*N* = 624)	*P*-Value
Age(years)			
Mean (SD)	46.6 (13.4)	46.8 (13.1)	0.816
Gender, n (%)			
Male	671 (46.1%)	294 (47.1%)	0.721
Female	783 (53.9%)	330 (52.9%)	
Hypertensives, n (%)			
No	1019 (70.1%)	417 (66.8%)	0.155
Yes	435 (29.9%)	207 (33.2%)	
Weight(Kg)			
Mean (SD)	69.0 (25.1)	68.6 (13.0)	0.896
Height(cm)			
Mean (SD)	164 (28.3)	164 (8.79)	0.503
Spot Urinary Sodium (mmol/L)			
Mean (SD)	149 (69.5)	148 (68.7)	0.954
Spot Urinary Potassium (mmol/L)			
Mean (SD)	47.1 (27.2)	47.8 (29.6)	0.999
Spot Urinary Creatinine (mmol/L)			
Mean (SD)	10.3 (4.75)	10.1 (4.93)	0.347
24-H Urinary Sodium (mg)			
Mean (SD)	3990 (1850)	4070 (1920)	0.498
24-H Urinary Potassium (mg)			
Mean (SD)	1770 (786)	1740 (737)	0.692
24-H Urinary Creatinine (mg)			
Mean (SD)	1120 (306)	1140 (327)	0.506

3.2 Validation of Equations Estimating 24-Hour Urinary Sodium Excretion

3.2.1 Correlations Between Estimated and Measured Sodium Excretion

The following study will examine the correlation between the actual and predicted 24-hour urinary sodium excretion values.

The validation set comprised 624 individuals. The correlation coefficients for the three equations fitted in this study were 0.447 (linear equation), 0.449 (power-law equation), and 0.502 (SMASH equation), while the correlation coefficients for the traditional three equations were 0.465 (Kawasaki equation), 0.424 (INTERSALT equation), and 0.459 (Tanaka equation). The correlation coefficients for all six equations were statistically significant (see Fig. 1). Among these, the SMASH model demonstrated the highest correlation coefficient (r = 0.502) among the six models, followed by the Kawasaki model's correlation coefficient (r = 0.465).

The differences between the predicted 24-hour urinary sodium values calculated using the three equations fitted in this study and the INTERSALT equation and the actual 24-hour urinary sodium values were not statistically significant, while the differences between the predicted 24-hour urinary sodium values calculated using the Kawasaki and Tannaka equations and the actual 24-hour urinary sodium values were statistically significant. The mean ± standard deviation of the actual 24-hour urinary sodium excretion was 4065.28 ± 1918.76 mg/24h (see Table 2).

Table 2
24-hour urinary sodium excretion (mg) calculated by six equations

Equations	**Mean ± SD**	**Bias**	**r**	***P*-value***
Linear Equation	4022.18 ± 907.37	43.10 ± 1717.46	0.447	0.531
Power-law Equation	4014.92 ± 912.43	50.36 ± 1715.00	0.449	0.463
SMASH Equation	4009.90 ± 970.46	55.37 ± 1659.78	0.502	0.404
Kawasaki Equation	5102.12 ± 1581.94	-1036.84 ± 1834.05	0.465	**<0.001**
Tanaka Equation	3858.98 ± 925.30	206.30 ± 1705.44	0.459	**0.012**
INTERSALT Equation	4061.62 ± 941.81	3.66 ± 1742.48	0.424	0.958

**P*-value means paired t test for Predicted 24-Hour Sodium Excretion and Measured 24-Hour Sodium Excretion. Bias is the difference between Predicted and Measured 24-Hour Sodium Excretion, expressed as mean ± standard deviation

3.2.2Assessment of Bias Between Predicted and Measured 24-Hour Sodium Excretion

In the Bland-Altman analysis, which compares the actual 24-hour urinary sodium values with the predicted 24-hour urinary sodium values calculated using six different equations, the SMASH model demonstrated the lowest standard deviation (1659.78), while the Kawasaki equation exhibited the highest standard deviation (1834.The standard deviation of the INTERSALT equation was found to be 1742.48. The Tanaka equation had a standard deviation of 1705.44, the linear equation had a standard deviation of 1717.46, and the exponential model had a standard deviation of 1715.00. With regard to the issue of bias, the Kawasaki equation demonstrated a bias of (bias = -1036.84 mg, 95% CI = -4631.58 to 2557.9), the INTERSALT equation exhibited a bias of (bias = 3.66 mg, 95% CI = -3411.61 to 3418.92), and the Tanaka equation revealed a bias of (bias = 206.30 mg, 95% CI = -3136.36 to 3548.In the 96th case, the linear equation demonstrated a bias of 43.10 mg (95% CI: -3323.12 to 3409.32). The exponential model exhibited a bias of 50.36 mg (95% CI: -3311.03 to 3411.76), while the SMASH model revealed a bias of 55.37 mg (95% CI: -3197.79 to 3308.54). The limits of consistency for the 24-hour urinary sodium predictions fitted by the six equations were all found to be relatively large (see Fig. 2). With regard to percentage error, the SMASH equation yielded the lowest result (80.02%), whilst the Kawasaki equation yielded the highest (88.43%). The Tanaka equation yielded 82.22%, the INTERSALT equation yielded 84.01%, the linear equation yielded 82.80%, and the exponential equation yielded 82.69%.

As demonstrated in Fig. 3, the discrepancy between the observed and predicted values of 24-hour urinary sodium excretion (Observed value - Predicted value) exhibits a marked increase as the observed value rises and a significant decrease as the observed value declines. This finding suggests that the predicted value may underestimate the actual value in individuals with high urinary sodium excretion and overestimate the actual value in individuals with low urinary sodium excretion.

3.2.3 Validation of the Predicting 24-Hour Sodium Excretion in Subgroups

In order to further assess the practical value of the model fitted in this study, participants were first divided into high-sodium excretion and low-sodium excretion groups based on the median 24-hour urinary sodium excretion (3752.1 mg) (see Appendix Table S1). In the low urinary sodium excretion group, the 24-hour urinary sodium predictions calculated by all six equations overestimated the actual 24-hour urinary sodium excretion. Among these, the SMASH equation demonstrated the highest correlation coefficient (r = 0.392), while the INTERSALT equation exhibited the lowest correlation coefficient (r = 0.229). In the high urinary sodium excretion group, with the exception of the Kawasaki equation, the remaining five equations underestimated the 24-hour urinary sodium excretion. Among the equations examined, the SMASH equation exhibited the highest correlation coefficient (r = 0.361), while the INTERSALT equation demonstrated the lowest correlation coefficient (r = 0.301).

The test set was divided into two groups: patients with non-hypertension and patients with hypertension. The correlation coefficients of the SMASH equations were found to be higher than those of the equations employed in previous studies, in both groups. The three equations fitted in this study are

applicable for population-level assessment, whereas the Kawasaki equations are not applicable for population-level assessment in either group of patients (see Appendix Table S2).

Finally, an in-depth analysis of the predictive results of the SMASH equation across different age groups was conducted (see Table S3). The highest correlation coefficient was observed in the 50–60 age group (r = 0.601), followed by the 20–30 age group (r = 0.520), and lowest in the 40–50 age group (r = 0.441). The variations in actual values and SMASH equation predictions across different age groups are illustrated in the supplementary figures S2 and figures S3.

4. Discussion

The present study developed prediction equations for estimating 24-hour urinary sodium excretion using spot urine data from the SMASH cohort in Shandong Province, tailored for the Shandong population. The resulting equations were then compared with traditional prediction equations. The findings indicated that the three prediction equations developed in this study were capable of predicting 24-hour urinary sodium excretion at the population level. However, they were not found to be suitable for individual-level predictions. In comparison with the three traditional equations, the SMASH equations exhibited the optimal predictive capacity. A stratified analysis was conducted, which revealed that the SMASH equations demonstrated superior fitting performance in populations with low sodium excretion, non-hypertensive populations, and the 50–60 age group.

The populations corresponding to traditional equations exhibit significant differences in diet, ethnicity, or living environment, resulting in poor consistency between predicted and actual values during extrapolation. Consequently, these equations are unable to accurately reflect an individual's true sodium excretion status. For instance, in 2021, Qian et al. discovered that the INTERSALT equation outperformed the Kawasaki and Tanaka equations in estimating 24-hour urinary sodium excretion in a population with primary hypertension in Northeast China [13]; In 2016, Xu et al. conducted a study on the prediction of 24-hour urinary sodium excretion in the Shandong Province population. This study found that the Tanaka equation outperformed the Kawasaki and INTERSALT equations, among five other prediction equations, at the population level (Xu et al., 2016) [14]. The findings of this study indicated that the Kawasaki equation exhibited a superior predictive capacity in comparison to the INTERSALT and Tanaka equations. However, its predictive ability was found to be inferior to that of the SMASH equation. This phenomenon may be attributable to the gradual convergence of the dietary structure of the population in Shandong Province with that of the Japanese diet, which is also characterised by high salt intake [15]. Conversely, as the intake of staple foods decreases, the recommended intake of fresh fruits, fats, fish, eggs, and dairy products shows an upward trend, and salt intake increases with the increase in fat and protein intake [16, 17]. In light of these dietary shifts, the Kawasaki equation, predicated on a high-salt diet, may no longer be applicable to the Shandong population. Consequently, the SMASH equation, which is more appropriate for the Shandong population, has clear public health significance.

In terms of group and individual predictive efficacy, the present study corroborates the findings of previous studies: the use of spot urine sodium to estimate 24-hour urine sodium excretion is more suitable at the group level than at the individual level. For instance, Brown et al., the developers of the INTERSALT equation, believed that the equation had broad applicability. However, given the heightened susceptibility of individual measurements to 'measurement error,' the accuracy of individual-level analysis is lower than that of group-level analysis [18]; Zhou et al. (2022) conducted a validation study of 141 community residents, the results of which indicated that the Kawasaki equation may provide the least biased information about average sodium intake at the population level. However, at the individual level, all three methods had high misclassification rates for salt intake groups [7]; Similar results to those of Zhou et al. were also verified in Peng et al.'s study of the PURE cohort [6]. On the population level, the SMASH equation exhibited a superior predictive capability in comparison to the other five equations. This may be attributed to the fact that the multiple linear regression model is capable of comprehensively considering multiple relevant factors, thereby fitting the most appropriate predictive equation for the Shandong Province population. The results of the Bland-Altman method indicated that the SMASH model and the other five equations were not suitable for individual-level predictions. This may be due to the fact that individual urinary sodium excretion is closely related to factors such as diet, smoking, alcohol consumption, and sleep quality. The employment of rudimentary physical measurement indicators in conjunction with a solitary urine sample is inadequate for the accurate evaluation of this phenomenon. As Naser et al. have suggested, after adjusting for covariates such as dietary habits, at least three non-consecutive 24-hour urine samples are required in order to assess an individual's daily dietary sodium intake [19]. It is also possible that the correlation between spot urine data collected at different time points and the actual 24-hour urinary sodium excretion varies. For instance, Shin et al. found that the correlation coefficient between the first morning spot urine sodium/spot urine creatinine and 24-hour urinary sodium/24-hour urinary creatinine was higher than that of evening and morning random urine [20], Mann et al. posit that the sodium/creatinine ratio in urine samples collected in the evening exhibits a strong correlation with the actual 24-hour sodium excretion [21], this discrepancy indicates the necessity for further research on urine samples collected at various time points.

Following the aggregation of sodium excretion levels, it was determined that the Kawasaki equation was the sole statistical model capable of being fitted at the population level in the high urinary sodium excretion group (≥ 3752.1 mg). This finding is consistent with those reported from populations in Tibet, Brazil, and Iran [22, 23]. This finding may be consistent with the characteristics of equation development in Japanese populations with high salt intake [11].

In the stratified analysis, the fitting performance of all six equations demonstrated a trend in which individuals with low urinary sodium excretion exhibited superior outcomes in comparison to those with high urinary sodium excretion, and non-hypertensive individuals demonstrated better outcomes than hypertensive individuals. The SMASH equation demonstrated superior fitting performance compared to the other five equations in both the low urinary sodium excretion group and the non-hypertensive group. Furthermore, the study demonstrated that the 50–60 age group exhibited superior fitting performance in

comparison to other age groups. This discrepancy may be ascribed to a number of factors. For instance, with regard to the selection of urine samples, Kawamura et al. proposed that the second morning urine sample is preferable to random urine samples when estimating daily salt intake in hypertensive patients [24]; Dyer et al. hypothesise that hypertensive patients may exhibit divergent sodium excretion rhythms in comparison to individuals with normal blood pressure [25]; Han et al. posit the hypothesis that distinct hypertension treatments exert an influence on salt excretion in individuals diagnosed with hypertension [26]. It is hypothesised that variations in the SMASH equation across different age groups may be attributable to the actual urinary sodium excretion levels in these groups. As the study progressed, it became evident that both the actual urinary sodium excretion levels and the predicted values calculated using the SMASH equation exhibited a trend of first increasing and then decreasing, as demonstrated in the supplementary figures (S2 and S3). This observation was consistent across both younger and older age groups. A comparable trend was also identified in a study by Rosa et al. on the Spanish population [27]. The present study also found that the difference between the actual and predicted values calculated by the six equations was significantly correlated with the actual 24-hour urinary sodium values, as illustrated in Fig. 3. The correlation coefficient between the difference calculated by the SMASH equation and the actual value was $r = 0.863$ ($P < 0.001$). In instances where the actual value was high, the predicted value exhibited a tendency to underestimate the actual value. Conversely, in instances where the actual value was low, the predicted value demonstrated a propensity to overestimate the actual value. Consequently, it is hypothesised that the true values of 24-hour urinary sodium excretion across various age demographics may exert an influence on the alterations in correlation coefficients observed between these demographics. However, current studies on predicting 24-hour urinary sodium based on spot urine sodium have limited in-depth analysis across different age groups. It is evident that further research is required in order to elucidate the underlying mechanisms and provide more precise predictions for populations of different age groups.

This study, which is based on reliable SMASH data, has pioneered the establishment of a predictive equation for estimating 24-hour urinary sodium levels using spot urine sodium measurements in the Shandong Province population. This is an advancement on previous studies, which had some limitations. However, the present study is not without its limitations, which include the presence of circadian rhythms in individual urinary sodium, urinary creatinine, and the urinary sodium-to-creatinine ratio [28, 29], In addition, the circadian rhythm of urinary sodium, potassium, and creatinine has been confirmed in the Chinese population. However, the urine samples collected for this study were exclusively obtained in the morning, precluding the possibility of selecting samples from other time periods for analysis. In comparison with multiple random urine samples, single spot urine samples are subject to certain limitations with regard to result interpretation and extrapolation [30]. Furthermore, the present study is deficient in accurate data on significant variables that have a substantial impact on urinary sodium excretion, such as participants' dietary habits and sleep quality. It is imperative that these aspects are addressed and enhanced in subsequent studies. Ultimately, the present study exclusively comprised permanent residents of Shandong Province, a factor which may constrain the generalisability of the results to a more extensive population.

5. Conclusions

The present study utilised three equations, based on anthropometric measurements and spot urine data, to predict 24-hour urinary sodium excretion. This was achieved by employing population data from Shandong Province, China. However, it should be noted that the three equations fitted in this study and the three equations from traditional studies are only applicable for population-level rather than individual-level estimation of urinary sodium excretion. In clinical settings, when studying different age groups, populations with or without hypertension, and populations with varying levels of urinary sodium excretion, it is important to carefully select between spot urine estimation methods and 24-hour urine collection methods.

Declarations

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Preventive Medicine Ethics Committee of Shandong Provincial Centre for Disease Control and Prevention (approval number 2016-7 from 29 April 2016).

Conflicts of Interest:

The authors declare no conflicts of interest.

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Author Contribution

Conceptualization: X.H. and C.X. ;methodology: J.T. and F.D.;validation: B.Z. ,J.R.and J.D.;writing original draft preparation, X.H.; writing—review and editing, X.H., X.G., and J.M. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The original contributions presented in the study are included in the article and Supplementary Materials; further inquiries can be directed to the corresponding authors.

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Figures

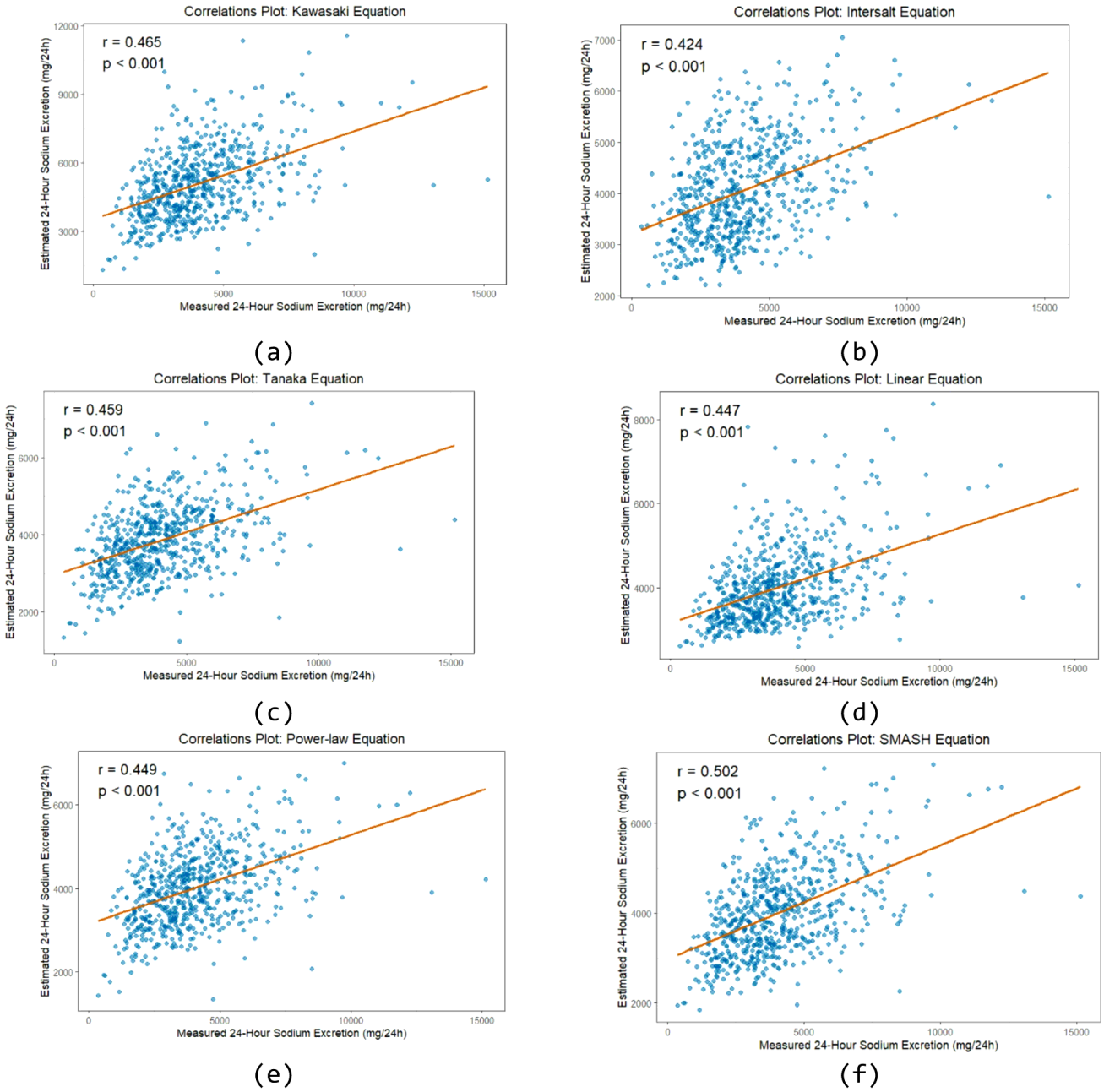


Figure 1

Correlation coefficients between measured and estimated 24-hour urinary sodium calculated by six equations.(a) Kawasaki equation; (b) INTERSALT equation; (c) Tanaka equation; (d) Linear equation; (e) Power-law equation; (f) SMASH equation

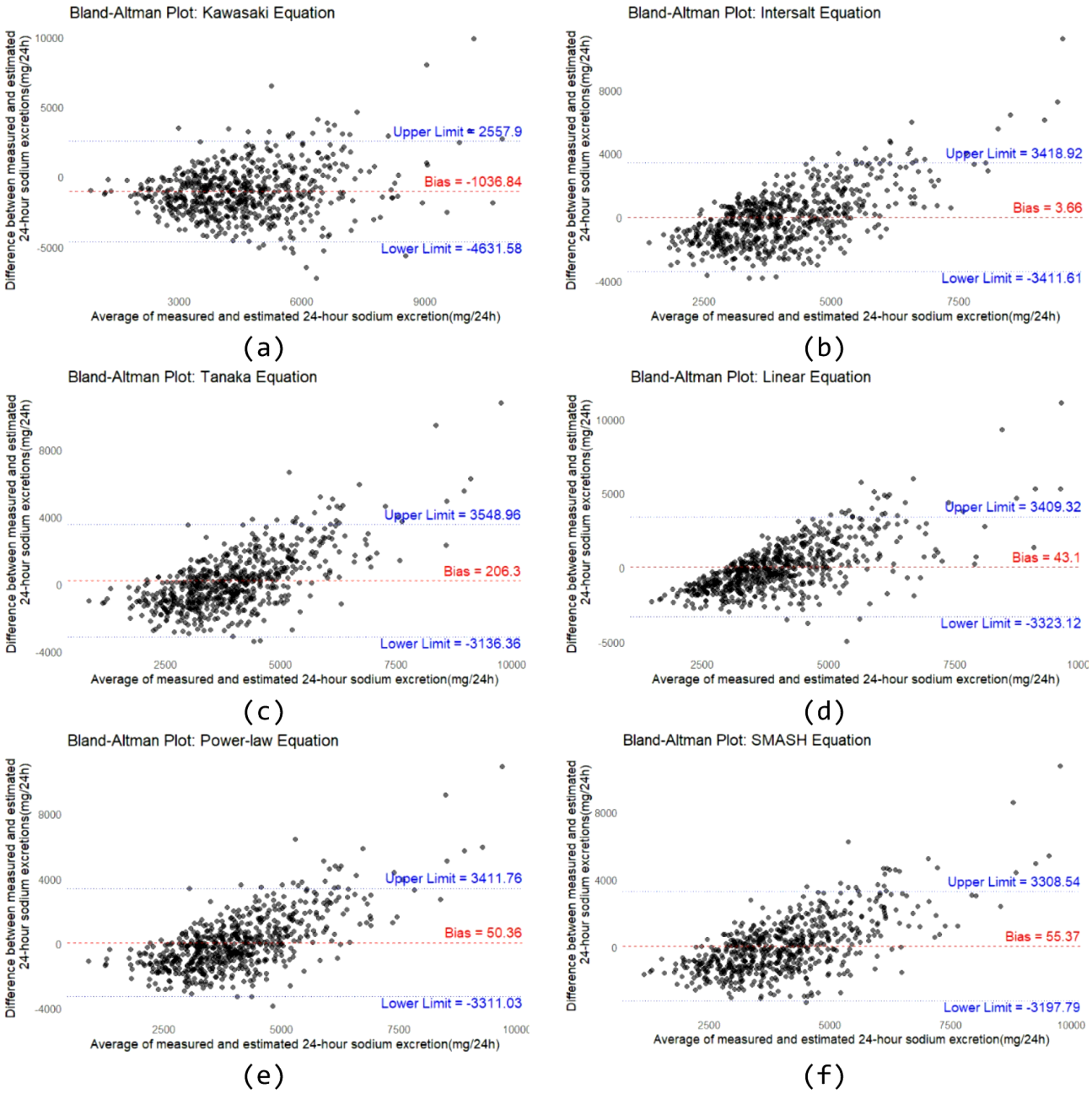


Figure 2

Bland-Altman analysis for agreement of the six equations. (a)Kawasaki equation; (b) INTERSALT equation; (c) Tanaka equation; (d) Linear equation; (e) Power-law equation; (f) SMASH equation

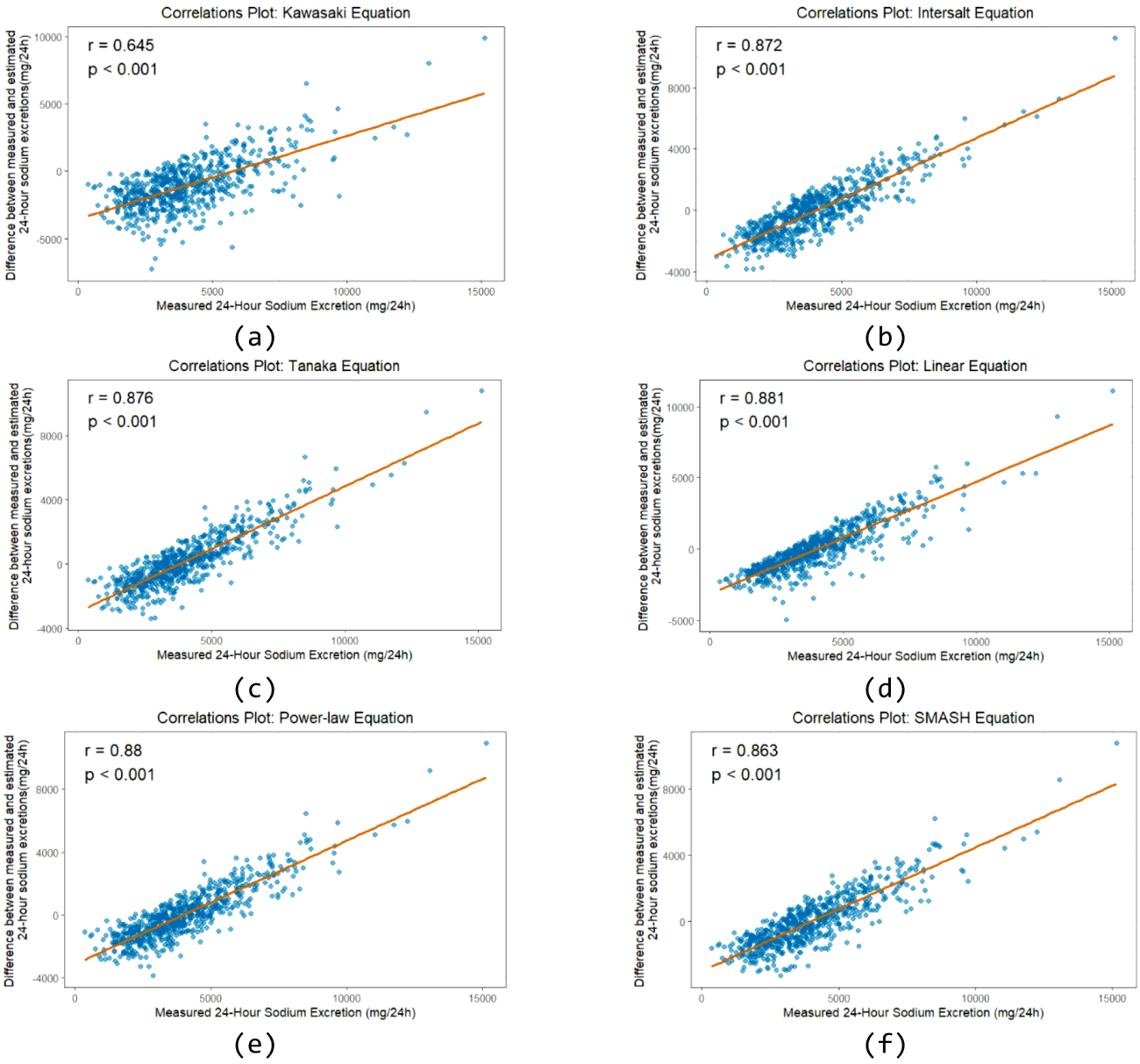


Figure 3

Relationship between the differences of measured and estimated 24-hour urine sodium against measured 24-hour urine sodium(a)Kawasaki equation; (b) INTERSALT equation; (c) Tanaka equation; (d) Linear equation; (e) Power-law equation; (f) SMASH equation

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