Validation of Spot Urine Sodium for Estimating 24-Hour Urine Sodium in Patients with Essential Hypertension: A Postprint

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Abstract

Background: Calculating sodium intake in patients with essential hypertension through 24-hour urinary sodium measurement is of great significance for guiding treatment, but the detection process is cumbersome. The predictive value of existing formulas for estimating 24-hour urinary sodium levels from spot urine sodium in Chinese patients with essential hypertension remains unclear.

Objective: To evaluate the accuracy of applying the Kawasaki, INTERSALT, and Tanaka formulas to estimate 24-hour urinary sodium from spot urine sodium in Chinese patients with essential hypertension.

Methods: We retrospectively analyzed data from 203 hospitalized patients with essential hypertension in the cardiology department from March 2018 to March 2021, including sex, age, comorbidities, spot urine sodium, and 24-hour urine sodium. Using paired t-test, correlation analysis, Bland–Altman plot, and other methods, we calculated the correlation and difference range between the 24-hour urinary sodium levels estimated by the three formulas and the actual measured values through SPSS 24.0; we evaluated the accuracy of the three estimation formulas in patients with different salt intake levels, diabetes, and proteinuria.

Results: A total of 196 cases were finally included in the analysis, with a mean urinary sodium excretion level of 165.04$±78.53*mmol/d, equivalenttoadailysodiumsaltintakeof*9.65±4.59*g.Th*
*hoururinarysodiumexcretionat*217.62±77.90*mmol/d, whichwashigherthanthemeasuredvalue, withastatistic*
0.001)*andacorrelationcoefficientof*0.391(*p* < 0.001).*TheINTERSALTmethodestimated*24−
*hoururinarysodiumexcretionat*143.69±45.30*mmol/d, whichwaslowerthanthemeasuredvalue, withastatistica*
0.001)*andacorrelationcoefficientof*0.456(*p* < 0.001).*TheTanakamethodestimated*24−
*hoururinarysodiumexcretionat*168.24±$47.32 mmol/d, which was higher than the measured value, with no statistically significant difference (p=0.585) and a correlation coefficient of 0.327 (p<0.001). Among the three methods, the Tanaka method' s estimated values were closest to the measured mean values

(relative deviation 1.90%). After grouping by salt intake, the correlation between predicted and measured values by each formula was no longer significant. Whether patients had diabetes or proteinuria had no statistically significant effect on the predictive accuracy of the formulas.

Conclusion: The accuracy and consistency of estimating 24-hour urinary sodium levels from spot urine sodium using the above three formulas in patients with hypertension are suboptimal.

Full Text

Validation Study on the Accuracy of Using Spot Urine Sodium to Estimate 24-Hour Urinary Sodium in Primary Hypertension Patients

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Abstract

Background: Estimating sodium intake in primary hypertension patients through 24-hour urinary sodium measurement is important for guiding treatment, but the testing process is cumbersome. The validity of existing equations for estimating 24-hour urinary sodium excretion from spot urine samples in Chinese primary hypertension patients remains unclear.

Objective: To evaluate the validity of the Kawasaki, INTERSALT, and Tanaka equations for estimating 24-hour urinary sodium from spot urine samples among Chinese primary hypertension patients.

Methods: We retrospectively analyzed data on gender, age, comorbidity, spot urinary sodium, and 24-hour urinary sodium from 203 hospitalized primary hypertension patients between March 2018 and March 2021. Using SPSS 24.0, we assessed validity by comparing predicted 24-hour urinary sodium excretion from spot urine with measured 24-hour urinary sodium excretion. Paired t-tests, Spearman correlation coefficients, and Bland-Altman plots were used to evaluate the accuracy of the three equations in patients with different salt intake levels, diabetes, or proteinuria.

Results: The average urinary sodium excretion level was 165.04$\pm$78.53 mmol/d, equivalent to a daily sodium chl
hour urinary sodium excretion at 217.62$\pm$77.90 mmol/d, significantly higher than measured values ($p < 0.001$), with a correlation coefficient of 0.391 ($p < 0.001$). The INTERSALT equation estimated 24-hour urinary sodium excretion at 143.69$\pm$45.30 mmol/d, lower than measured values ($p < 0.001$), with a correlation coefficient of 0.456 ($p < 0.001$). The Tanaka equation estimated 24-

*hoururinarysodiumexcretionat*168.24±$47.32 mmol/d, higher than measured values but without statistical significance (p=0.585), with a correlation coefficient of 0.327 (p<0.001). Among the three equations, Tanaka' s overall estimated value was closest to the measured mean (relative deviation 1.90%). After stratifying patients by salt intake, correlations between predicted and actual values were no longer significant. There was no significant difference in predictive accuracy between patients with and without diabetes or proteinuria.

Conclusion: The accuracy and consistency of the three equations for estimating 24-hour urinary sodium levels from spot urine in primary hypertension patients were poor.

Keywords: primary hypertension; spot urine sodium; 24-hour urinary sodium

Introduction

Hypertension is a disease caused by multiple genetic and environmental factors[1] and represents an important controllable risk factor for stroke, heart failure, ischemic heart disease, and other conditions[2]. A low-salt diet can reduce blood pressure, with a reduction of 100 mmol/d in salt intake associated with a 7/4 mmHg decrease in blood pressure[3]. The World Health Organization (WHO) currently recommends daily salt (sodium chloride) intake below 5 g, yet studies show that the global average intake is 9.87 g, with 99.2% of countries exceeding WHO standards[4]. Targeted dietary intervention and guidance for hypertensive patients with excessive salt intake would yield greater cost-effectiveness. Currently, the gold standard for assessing salt intake levels is 24-hour urinary sodium excretion, but this testing method is time-consuming and cumbersome, limiting its clinical application. A simpler approach involves using spot urine sodium levels from a single urine sample to estimate 24-hour urinary sodium. If this simplified sampling method could be used to estimate 24-hour urinary sodium in hypertensive patients, thereby assessing their salt intake and enabling precise dietary guidance, it would be more conducive to achieving blood pressure targets and reducing related complications.

Commonly used formulas for estimating 24-hour urinary sodium from spot urine include the Kawasaki formula[5], the INTERSALT (International Cooperative Study on Salt, Other Factors, and Blood Pressure) formula[6], and the Tanaka formula[7] (hereinafter referred to as the K-method, I-method, and T-method, respectively). Among these three formulas, the K-method was developed in Japanese healthy populations, while the other two involved European and American participants in nutritional epidemiology surveys (the Tanaka formula selected Japanese data from the INTERSALT study). None of these represent Chinese hypertensive patients. Moreover, the proportion of salt-sensitive individuals (those with blood pressure elevation after salt loading) is relatively large among Chinese hypertensive patients, and sodium excretion processes involving multiple renal and extrarenal factors show significant differences across races and comorbidities such as hypertension[8-10]. The accuracy of using these three formulas to estimate 24-hour urinary sodium from spot urine levels has not been validated in Chinese primary hypertension populations.

Methods

1.1 Study Subjects

This was a retrospective study that included hypertensive patients hospitalized in the Department of Cardiology at Peking University International Hospital from March 2018 to March 2021. Inclusion criteria were: (1) age 18 years or older, regardless of gender; (2) clinically diagnosed primary hypertension (stages I-III); (3) no diuretics at conventional or higher doses (hydrochlorothiazide $ $25 mg or indapamide $ $2.5 mg) within 2 weeks; (4) completed 24-hour urinary sodium and creatinine measurements; and (5) completed spot urine sodium, potassium, and creatinine measurements, with available data on height, weight, age, comorbidities, and medications.

Exclusion criteria were: (1) secondary hypertension; (2) renal insufficiency (estimated glomerular filtration rate, eGFR <60 ml/min); (3) type 1 diabetes (insulin users) and poorly controlled type 2 diabetes (glycated hemoglobin >8.0% or fasting blood glucose >11.0 mmol/L); (4) use of medications affecting sodium absorption and excretion, such as tolvaptan; or presence of diseases affecting sodium absorption and excretion, such as severe diarrhea, heart failure, hepatic insufficiency; or special conditions such as pregnancy or eating disorders.

This study was approved by the Biomedical Ethics Committee of Peking University International Hospital (approval number: 2022-KY-0018-01) and complied with the Declaration of Helsinki.

1.2 Research Methods

1.2.1 24-hour urine specimen collection: Patients maintained their normal diet during hospitalization. Within 2-5 days after admission, collection began after the first morning void and continued for 24 hours, with all urine stored in a collection container. After completing the 24-hour collection, the total urine volume was measured and recorded, and 10 ml of mixed urine from the container was sent for testing. All urine specimens were delivered to the laboratory within 2 hours for measurement of urinary sodium concentration. Twenty-four-hour urinary sodium (mmol/d) was calculated as measured urinary sodium concentration (mmol/L) $\times$ 24-hour urine volume (L/d).

1.2.2 Spot urine sodium, potassium, and creatinine collection: Ten milliliters of morning urine were collected in a tube and sent for testing. The spot urine specimen was collected within 48 hours of the 24-hour urine collection.

1.2.3 Estimating 24-hour urinary sodium from spot urine sodium: The three formulas in Table 1 were used to calculate estimated values, which were compared with actual measured values.

Table 1 Three equations using spot urine samples to estimate 24-hour urinary sodium excretion

Formula Name	Main Study Population Source	Spot Urine Sample Type	24-hour Urinary Sodium Excretion Estimation Formula
Kawasaki	Japanese healthy population	Second morning void after overnight fast	24-hour urinary sodium excretion = 16.3 × (spot urine sodium/spot urine creatinine × 24-hour urine creatinine)^0.524-hour urine creatinine (male) = 15.12 × weight + 7.39 × height - 12.63 × age - 79.924-hour urine creatinine (female) = 8.58 × weight + 5.09 × height - 4.72 × age - 74.5
INTERSALT	North America and Europe	Random spot urine	24-hour urinary sodium excretion estimate (male) = 25.46 + 0.46 × spot urine sodium - 2.75 × spot urine creatinine - 0.13 × spot urine potassium + 4.1 × BMI + 0.26 × age24-hour urinary sodium excretion estimate (female) = 5.07 + 0.34 × spot urine sodium - 2.16 × spot urine creatinine - 0.09 × spot urine potassium + 2.39 × BMI + 2.35 × age - 0.03 × age^2
Tanaka	Japanese from INTERSALT study	Random spot urine	24-hour urinary sodium excretion estimate = 21.98 × (spot urine sodium/spot urine creatinine × 24-hour urine creatinine)^0.39224-hour urine creatinine = 14.89 × weight + 16.14 × height - 2.04 × age - 2244.45

Note: Units: spot urine sodium: mmol/L; spot urine creatinine: mg/L (K-method, T-method), mmol/L (I-method); 24-hour urine creatinine: mg/d (K-method, T-method), mmol/d (I-method); 24-hour urinary sodium estimate: mmol/d; spot urine potassium: mmol/L; height: cm; weight: kg; BMI: kg/m^2

1.3 Statistical Methods

Descriptive statistics were performed on measured 24-hour urinary sodium values, and outliers were excluded after constructing box plots. The remaining patient data were used for statistical analysis. For baseline characteristics, continuous variables were expressed as mean ± standard deviation, and categorical variables were recorded as frequencies and percentages. For between-group comparisons, continuous variables were analyzed using t-tests, and categorical variables were analyzed using chi-square tests.

To compare differences between measured 24-hour urinary sodium values and estimated values calculated from spot urine using the three formulas (hereinafter referred to as estimated values): paired t-tests were used to assess the significance of differences; Spearman correlation analysis was used to evaluate correlations. The absolute difference between measured and estimated values was calculated and divided by the measured value to obtain relative deviation. Bland-Altman plots were used to evaluate agreement between measured and estimated 24-hour urinary sodium values. The ratio of geometric means between measured and estimated 24-hour urinary sodium values was used to quantify differences between the two.

According to the sodium intake classification standards of the National Basic Public Health Service, patients were divided into four groups based on 24-hour salt intake: <6.0 g, 6-8.9 g, 9-11.9 g, and $ $12 g, corresponding to measured 24-hour urinary sodium excretion values of <102.56 mmol, 102.56-152.14 mmol, 152.14-203.42 mmol, and $ $203.42 mmol, respectively. The agreement of the three formulas was compared within each of the four salt intake groups. Additionally, patients were grouped by gender, presence of diabetes, and presence of proteinuria (24-hour urinary protein excretion/creatinine $ $30 mg/g) to compare the agreement of the three formulas within each subgroup.

All statistical analyses used two-tailed tests, with P<0.05 considered statistically significant. Statistical analyses were performed using SPSS 24.0. Bland-Altman plots were generated using Medcalc Version 20.014.

Results

2.1 Baseline Characteristics of Enrolled Primary Hypertension Patients

A total of 203 patients met the inclusion criteria. Descriptive analysis of measured 24-hour urinary sodium values was performed, and box plots were constructed based on median and quartile values. Seven outliers (4 males and 3 females) were identified and excluded due to unreliable urinary sodium levels. The final analysis included 196 patients (91 females and 105 males) with a mean age of 57.11$±14.55years.Theaverageurinarysodiumexcretionlevelwas165.04±78.53mmol/d, equivalenttoadailys
0.001), hadlowerbodymassindex(BMI)(26.14±4.15vs.27.49±3.67kg/m^{2}, p =
0.027), lowermeandiastolicbloodpressure(71.48±11.32vs.78.19±13.12mmHg, p <

0.001), andhigherprevalenceofproteinuria(31.1±49.49vs.134.44±56.54mmol/L, p < 0.001).Theaverage24−hoururinarysodiumexcretionwas134.86±62.90mmol/dinfemalepatients(equivalentto g/d of sodium chloride), with females having significantly lower salt intake than males (p<0.001) (see Table 2 for details).

Table 2 Baseline characteristics of enrolled patients with primary hypertension

Item	All (n=196)	Female (n=91)	Male (n=105)	Chi-square/T value	P value
Gender	91 (46.4%)	105 (53.6%)	-	-	-
Age (years, mean±SD)	57.11±14.55	63.02±12.05	52.3[illegible]4.66	–	< 0.001 *
BMI (kg/m^{2}, mean±SD)	26.85±3.88	26.14±4.15	27.49±3.67	–	0.027 *
Admission SBP (mmHg, mean±SD)	149.13±19.58	150.55±19.89	147.68±19.45	–	–
Admission DBP (mmHg, mean±SD)	82.24±15.60	79.33±14.59	84.52±16.05	–	0.006 *
24-hour mean SBP (mmHg, mean±SD)	130.11±17.15	130.08±17.67	129.82±17.25	–	–
24-hour mean DBP (mmHg, mean±SD)	75.03±12.70	71.48±11.32	78.19±13.12	–	< 0.001 *
24-hour mean heart rate (bpm, mean±SD)	70.30±9.38	69.34±9.61	70.97±9.32	–	–
Abnormal nocturnal BP dipping (n, ±SD)	117.52±55.28	101.35±49.49	134.44±56.54	–	< 0.001 *
Measured 24-hour urinary sodium (mmol/d, mean±SD)	165.04±78.53	134.86±62.90	193.11±82.00		

Note: * indicates statistically significant difference between groups

2.2 Agreement Between K-Method Estimated and Measured 24-Hour Urinary Sodium Excretion

The K-method estimated 24-hour urinary sodium excretion at 217.62±77.90mmol/d, whichwas52.52±91.58 mmol/d higher than the measured value, with the paired t-test showing a statistically significant difference (p<0.001). Correlation analysis revealed a moderate correlation between estimated and measured values (correlation coefficient 0.391, p<0.001). The geometric mean ratio of measured to estimated 24-hour urinary sodium excretion was 0.709, indicating that estimated values were overestimated. Bland-Altman plot analysis (Figure 1 [Figure 1: see original paper]) identified 10 data points (5.13%) outside the 95% limits of agreement, reflecting poor consistency. When grouped by clinical characteristics, the correlation was better in female patients than in male patients, while there was little difference between patients with and without diabetes or proteinuria. After grouping by salt intake, the originally moderate correlation was significantly weakened; except for the group with salt intake below 6 g, the other three groups showed no significant correlation between estimated and measured values (Table 3).

Table 3 The difference and correlation between the estimated 24-hour urinary sodium excretion of K method and the measured value

<table>
<tr><th>Item (n)</th><th>Measured 24-hour urinary sodium (mmol/d)</th><th>K-method estimated value (mmol/d)</th><th>Absolute difference (mmol/d)</th><th>Paired t-test T value</th><th>Correlation coefficient (Spearman)</th></tr>
<tr><td>All (196)</td><td>165.04$±78.53|217.62±77.90|−
52.52±91.58| −
| < 0.001 ∗
||Female(91)|134.86±62.90|194.97±77.90|−
60.13±91.58| −
| < 0.001 ∗
||Male(105)|193.11±82.00|237.44±77.90|−
45.86±91.58| −
|0.047 ∗
||Diabetes(53)|155.70±78.53|219.20±77.90|−
63.51±91.58| −
|0.002 ∗ ||Non−
diabetes(143)|168.62±78.53|217.03±77.90|−
48.42±91.58| −
| < 0.001 ∗
||Albuminuria(57)|152.12±78.53|235.92±77.90|−
83.80±91.58| −
|0.005 ∗
||Noalbuminuria(139)|169.15±78.53|211.96±77.90|−
42.81±91.58| −
| < 0.001 ∗
||Saltintake <
6g(40)|67.18±24.42|164.38±77.90|−
97.20±91.58| −
|0.045 ∗
||Saltintake6 −
9g(51)|127.33±78.53|207.76±77.90|−
80.43±91.58| −
| −
||Saltintake9 −
12g(57)|175.86±78.53|243.11±77.90|−
67.24±$91.58</td><td>-</td><td>-</td><td></td><td></td></tr>
<tr><td>Salt intake</td><td>-</td><td>0.011*</td><td></td><td></td><td></td></tr>
<tr><td colspan="6">$ 12g(47)|276.39±78.53|242.73±77.90|33.67±$91.58</td></tr>
</table>

Note: * indicates statistical significance

Figure 1 [Figure 1: see original paper] The consistency of measured and estimated 24-hour urine sodium excretion by K method was evaluated by Bland-

Altman plots

2.3 Agreement Between I-Method Estimated and Measured 24-Hour Urinary Sodium Excretion

The I-method estimated 24-hour urinary sodium excretion at 143.69$±45.30mmol/d, lowerthantheK−methodand21.36±$71.76 mmol/d below the measured value, with the paired t-test showing a statistically significant difference (p<0.001). Correlation analysis revealed a moderate correlation between estimated and measured values (correlation coefficient 0.456, p<0.001). The geometric mean ratio of measured to estimated 24-hour urinary sodium excretion was 1.061, indicating that estimated values were underestimated. Bland-Altman plot analysis (Figure 2 [Figure 2: see original paper]) identified 11 data points (5.61%) outside the 95% limits of agreement, reflecting poor consistency. When grouped by clinical characteristics, the correlation was better in female patients than in male patients, while there was little difference between patients with and without diabetes or proteinuria. After grouping by salt intake, the originally moderate correlation disappeared (Table 4).

Table 4 The difference and correlation between the estimated 24-hour urinary sodium excretion of I method and the measured value

Item (n)	Measured 24-hour urinary sodium (mmol/d)	I-method estimated value (mmol/d)	Absolute difference (mmol/d)	Paired t-test T value	Correlation coefficient (Spearman)
All (196)	165.04±78.53	143.69±45.30	21.36±70.27	4.167	<0.001*
Female (91)	134.86±62.90	107.69±45.30	27.16±55.37	4.678	<0.001*
Male (105)	193.11±82.00	174.89±45.30	16.33±83.35	−	0.047*
Diabetes (53)	155.70±78.53	139.43±45.30	16.26±71.70	−	<0.001*
Non-diabetes (143)	168.62±78.53	145.26±45.30	23.24±71.94	3.864	<0.001*
Albuminuria (57)	152.12±78.53	140.23±45.30	11.90±69.18	−	0.006*
No albuminuria (139)	169.15±78.53	145.15±45.30	24.00±72.65	4.018	<0.001*
Salt intake <6g (40)	67.18±24.42	113.23±45.30	−46.05±44.32	−6.751	<0.001*
Salt intake 6−9g (51)	127.33±78.53	129.36±45.30	−2.03±45.02	−	−
Salt intake 9−12g (57)	175.86±78.53	155.47±45.30	19.99±45.98	-	<0.001*
Salt intake 12g (47)	276.39±78.53	170.61±45.30	105.78±59.15		

Note: * indicates statistical significance

Figure 2 **[Figure 2: see original paper]** The consistency of measured and estimated 24-hour urine sodium excretion by I method was evaluated by Bland-Altman plot

2.4 Agreement Between T-Method Estimated and Measured 24-Hour Urinary Sodium Excretion

The T-method estimated 24-hour urinary sodium excretion at 168.24±47.32 mmol/d, which was 3.14±80.03 mmol/d higher than the measured value, with the paired t-test showing no statistically significant difference (p=0.585). Compared with the K- and I-methods, the T-method estimated values were closest to the measured values. Correlation analysis revealed a moderate correlation between estimated and measured values (correlation coefficient 0.327, $p<0.001$). The geometric mean ratio of measured to estimated 24-hour urinary sodium excretion was 0.894, indicating that estimated values were slightly overestimated. Bland-Altman plot analysis (Figure 3 [Figure 3: see original paper]) identified 7 data points (3.59%) outside the 95% limits of agreement, reflecting fair consistency that was superior to the K- and I-methods. When grouped by clinical characteristics, the correlation was better in female patients than in male patients, while there was little difference between patients with and without diabetes or proteinuria. After grouping by salt intake, the originally moderate correlation disappeared (Table 5).

Table 5 The difference and correlation between the estimated 24-hour urinary sodium excretion of T method and the measured value

<table>
<tr><th>Item (n)</th><th>Measured 24-hour urinary sodium (mmol/d)</th><th>T-method estimated value (mmol/d)</th><th>Absolute difference (mmol/d)</th><th>Paired t-test T value</th><th>Correlation coefficient (Spearman)</th></tr>
<tr><td>All (196)</td><td>165.04$±78.53|168.24±47.32|−3.14±80.03|−|< 0.001∗||Female(91)|134.86±62.90|161.87±47.32|−27.03±57.00|−|< 0.001∗||Male(105)|193.11±82.00|173.81±47.32|17.77±90.99|−|0.049∗||Diabetes(53)|155.70±78.53|170.19±47.32|−14.50±79.00|−|0.005∗||Non−diabetes(143)|168.62±78.53|167.51±47.32|1.11±80.27|−|< 0.001∗||Albuminuria(57)|152.12±78.53|181.17±47.32|−29.06±73.10|−|0.010∗||Noalbuminuria(139)|169.15±78.53|164.15±47.32|5.00±80.87|−|< 0.001∗||Saltintake < 6g(40)|67.18±24.42|137.89±47.32|−70.71±43.22|−|< 0.001∗||Saltintake6−9g(51)|127.33±78.53|163.10±47.32|−35.77±48.36|−|< 0.001∗||Saltintake9−12g(57)|175.86±78.53|185.03±47.32|−9.17±$48.13</td><td>-</td><td>-</td><td></td><td></td></tr>
<tr><td>Salt intake</td><td>-</td><td><0.001*</td><td></td><td></td><td></td></tr>
<tr><td colspan="6">$ 12g(47)|276.39±78.53|179.30±47.32|97.09±$67.87</td></tr>
</table>

Note: * indicates statistical significance

Figure 3 [Figure 3: see original paper] The consistency of measured and estimated 24-hour urine sodium excretion by T method was evaluated by Bland-Altman plot

2.5 Comparison of the Three Estimation Methods

Comparing the three methods, the T-method' s overall estimated values were closest to the measured values (relative deviation 1.90%), while the K-method showed the largest deviation (relative deviation 31.82%). Both the T- and K-methods overestimated values, whereas the I-method underestimated them. In comparisons across different salt intake groups, the I-method showed the smallest estimation deviation in the 6-9 g/d sodium chloride intake group (relative deviation 1.57%); the T-method showed the smallest deviation in the 9-12 g/d group (relative deviation 5.21%); the K-method showed the smallest deviation in the >12 g/d group (though still high at 38.23% relative deviation); and for the <6 g/d group, all methods were relatively inaccurate, with the I-method showing the smallest deviation at 68.55% relative deviation.

Discussion

Numerous clinical data demonstrate that restricting salt intake can improve blood pressure control[12], and hypertension guidelines worldwide clearly recommend salt limitation[13]. Currently, the average daily salt intake among Chinese adults is 9.3 g, which, despite a gradual downward trend, remains nearly double the WHO recommended level[14]. This study further shows that primary hypertension patients have a higher average daily salt intake of 9.65 g, exceeding the adult average. Therefore, simple and accurate assessment of salt intake levels is of great importance for hypertension management.

Current methods for assessing salt intake levels include questionnaire surveys and 24-hour urinary sodium measurement, with the latter considered more accurate[15,16]. However, 24-hour urine collection has high requirements for storage equipment, storage environment, and patient compliance, and is more expensive. Additionally, three methods estimate 24-hour urinary sodium levels through single urine sodium measurements: the Kawasaki formula[5], the INTERSALT formula[6], and the Tanaka formula[7]. The Kawasaki formula was developed using regression analysis of next-day fasting morning urine and 24-hour urinary sodium from 159 Japanese individuals, with specific timing requirements for spot urine sodium measurement. The INTERSALT study collected random urinary sodium and 24-hour urinary sodium data from 10,079 individuals aged 20-59 years from 32 countries, primarily in Europe and North America, and derived formulas through regression methods. Some studies have shown high estimation accuracy for the INTERSALT formula, but the urinary sodium levels in that study population (4.09±1.60 g/d in males, 2.98±1.09 g/d in females)[17] were lower than in our study (4.44±1.89 g in males, 3.10±1.4 g in females). Our results similarly suggest that the I-method has higher accuracy at lower sodium intake levels.

The Tanaka formula was derived using Japanese data selected from the INTERSALT study. Since Japanese salt intake is significantly higher than that of Europeans, this formula has certain reference value for Chinese populations with similar dietary habits. Our study similarly indicates that the T-method estimated values were closest to measured values and was most accurate in the 9-12 g salt intake group, which approximates the average salt intake level in our study. However, all three formulas were developed through sampling and modeling in general populations, and their applicability to hypertensive populations remains unclear.

Hypertensive patients have higher salt intake levels than the general population[18], and Chinese hypertensive patients are generally salt-sensitive, with increased sodium intake more closely correlated with blood pressure elevation[19]. Currently, few studies have used spot urine sodium to estimate 24-hour urinary sodium levels in Chinese hypertensive patients. Jiang et al.[20] collected fasting morning spot urine from 264 hypertensive patients and estimated 24-hour urinary sodium using the three formulas, with results showing the T-method was most accurate, similar to our study' s conclusion. However, the correlation coefficients between estimated and actual values in that study ranged from 0.55-0.68, indicating moderate-to-strong correlation, possibly due to lower salt intake levels in that study population. That study did not, however, examine the accuracy of formula estimations across different salt intake groups.

This study collected 24-hour urine for sodium measurement in primary hypertension patients and performed correlation analysis with morning urine sodium levels. Results showed that the T-method' s overall estimated values were closest to the measured mean values and was most accurate at daily salt intake of 9-12 g. However, this method still had large deviations for populations with excessive or insufficient salt intake. Huang' s study similarly demonstrated that formula-estimated urinary sodium levels were insufficient to distinguish sodium excretion between low-sodium salt intervention and control groups in Chinese populations[21], and recommended against using spot urine sodium to estimate 24-hour urinary sodium at the individual level[22]. Our study did not find that diseases potentially affecting urinary sodium excretion (such as diabetes, proteinuria) had significant effects on estimation formula accuracy, though previous published studies have not focused on these conditions.

This study has several limitations. First, the sample size was relatively small. To detect a correlation coefficient $ $0.2 at a 5% significance level with >80% statistical power, 193 patients would be needed. Our study included 196 patients, which met this requirement and could reflect significant correlations between formula-estimated and measured values. However, after grouping by salt intake level, the small number of patients in each group led to significantly weakened data correlations. Additionally, considering compliance and convenience of specimen collection, we did not perform multiple measurements of spot urine sodium and 24-hour urinary sodium to increase the stability and accuracy of results. This study used morning urine for spot urine sodium measurement, but human diet, water intake, and body temperature vary throughout the day, so morning urine sodium may not be representative. Finally, the average salt intake level in Chinese primary hypertension populations differs from that of the populations used to develop the three formulas, which would affect prediction accuracy.

In summary, the Kawasaki, INTERSALT, and Tanaka formulas all have biases when predicting 24-hour urinary sodium from spot urine in primary hypertension patients, but the T-method has the smallest deviation and is most accurate in the group with daily sodium intake of 9-12 g. However, for patients with excessively high or low salt intake, all formulas show large prediction deviations. For hypertensive patients and patients with different salt intake levels, more accurate prediction formulas need to be explored to estimate salt intake levels from spot urine at the individual level, thereby guiding personalized treatment plans.

Author Contributions

Sun Xinghe conceived the research direction, collected and organized case data, performed statistical analysis, and wrote the initial draft; Wang Yang participated in case data collection and organization; Kang Junping was responsible for proofreading and revising the manuscript; Liu Xiaohui was responsible for quality control and review of the article and takes overall responsibility for the article; all authors approved the final manuscript.

Conflict of Interest

This article has no conflicts of interest.

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Note: Figure translations are in progress. See original paper for figures.