Systematic Review and Meta-Analysis

Evaluation of three prediction formulas of 24-hour urinary sodium excretion in Chinese residents: a systematic review and meta-analysis

Zijing Qi[1], Shuai Tang[1], Beike Wu[2], Yanxing Li[1], Hongmei Yang[3], Kunbo Wang[4] and Zhifang Li[3,1,*]

[1]School of Public Health, Shanxi Medical University, Taiyuan 031000, China: [2]School of Public Health, Harbin Medical University, Harbin 150081, China: [3]Department of Public Health and Preventive Medicine, Changzhi Medical College, Changzhi 046000, China: [4]CLASS 2202, Xiangya School of Medicine, Central South University, Changsha 410000, China

Abstract

Objective: To determine the appropriateness of three widely used formulas estimating 24-h urinary Na (24hUNa) from spot urine samples in the Chinese population.
Design: Systematic review and meta-analysis.
Setting: Literature review was conducted to identify studies for estimating 24hUNa using the Kawasaki, Tanaka and INTERSALT formulas simultaneously in PubMed, Embase and the Cochrane library databases. The mean difference (MD) and correlation coefficients (r) between measures and estimates from different formulas were assessed.
Participants: Information extraction and quality assessment were performed in thirteen studies involving 8369 subjects.
Results: Two studies which affected the overall robustness were excluded in the 'leave-one-out' sensitivity analyses. Within the final meta-analysis included eleven studies and 7197 participants, 36·07 mmol/d (95 %CI 16·89, 55·25) of MD was observed in the Kawasaki formula, and −19·62 mmol/d (95 %CI −37·37, −1·87) in the Tanaka formula and −35·78 mmol/d (95 %CI −50·76, −20·80) in the INTERSALT formula; a pooled r-Fisher's Z of 0·39 (95 %CI 0·32, 0·45) in the Kawasaki formula, 0·43 (95 %CI 0·37, 0·49) in the Tanaka formula and 0·36 (95 %CI 0·31, 0·42) in the INTERSALT formula. Subgroup analyses were conducted to explore the possible factors affecting the accuracy of the formula estimation from three mainly aspects: population types, Na intake levels and urine specimen types.
Conclusions: The meta-analysis suggested that the Tanaka formula performed a more accurate estimate in Chinese population. Time of collecting spot urine specimens and Na intake level of the sample population might be the main factors affecting the accuracy of the formula estimation.

Globally, excessive salt intake is recognised as a public health issue[1]. In 2013, the WHO recommended for a 30 % reduction in daily salt intake, aiming for a population salt reduction target of less than 5 g per day per individual by 2025, as a global salt reduction initiative[2]. To achieve this goal, a series of salt reduction strategies have been promoted in China[3]. Regularly monitoring population salt (Na) intake[4] is a common approach to assess the effectiveness of salt reduction strategies[5]. While 24-h urine collection is esteemed as the gold standard for assessing population Na intake, its practicality in extensive epidemiological research[6] is curtailed by inherent challenges such as the significant burden of collection, elevated costs and the prevalence of incomplete collections[6]. The

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Zijing Qi and Shuai Tang contributed equally to this work.

measurement of Na in a spot urine has the potential to estimate the 24-h urinary Na (24hUNa)[7], when assessing Na intake at the population level[8]. Currently, there are three widely used formulas estimating 24hUNa from spot urine samples among Chinese population including the Kawasaki formula[9], the Tanaka formula[10] and the INTERSALT formula[11]. The appropriateness of the three formulas has not been systematically evaluated due to their diverse predictive results in different studies[12–19]. The aim of this meta-analysis is to identify which formula could produce a more accurate estimate in the Chinese population.

Methods

Databases and search terms

The systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist[20]. A combination of terms was used to search the titles and abstracts of publications in PubMed, Embase and the Cochrane library, including 'spot urine' AND 'sodium' AND 'China' (Chinese residents). Search results were imported to EndNote X9 (Clarivate Analytics, 2019) for screening and extraction. The literature screening process is illustrated in Fig. 1.

Inclusion and exclusion criteria

All eligible studies need to meet the criteria below:

(1) Type of participants. Participants included healthy or high-risk people of any age from any region of China; and
(2) Type of outcome measures. Studies reported mean Na intake by estimation of spot urine and 24-h urine collection specimens at the same time; and
(3) Method of validation. The Kawasaki, Tanaka and the INTERSALT formulas were used to report the estimates and measures (mean ± SD) at the same time; and
(4) Language. All studies were published in English; and
(5) Studies were eligible if published before November 2022.

Studies were excluded if they did not provide the measure of 24hUNa and estimates from spot urine using the three formulas simultaneously.

Study screening and data extraction

All titles and abstracts of included studies were initially screened by two reviewers (ZQ, ST), and the full text of potentially relevant articles was further reviewed. Then, the two reviewers independently extracted relevant data as follows: the first author, publication year, area studied, study population, sample size, female proportion, mean age (age range), fasting or not, type of spot urine sample, measured 24hUNa (mean ± SD), the formula used, estimated 24hUNa (mean ± SD) and correlation coefficients (r).

Reviewers resolved disagreements through consulting senior researchers (ZL) if necessary, during the study screening, review and data extraction. Details of the included thirteen studies are summarised in Table 1.

Statistical analysis

Pooled mean difference (MD) and pooled r-Fisher's Z of the three formulas were calculated using the Sidik–Jonkman method[21] for random-effect models. Sensitivity analyses were carried out by the 'leave-one-out' method, which removed one study at a time to check the robustness of the result. If the pooled results showed relatively large biases when a study was excluded, it suggests that the study had a significant impact on the overall results of meta-analysis, leading to its exclusion. Heterogeneity between studies was reflected by I^2 tests. Subgroup analyses were also implemented to detect potential sources of heterogeneity: (1) population subgroup (healthy or high-risk population), (2) Na intake subgroup (more than 10 g/d group or no more than 10 g/d group) and (3) urine sample type subgroup (casual spot urine, morning urine or fasting morning urine). The meta-analysis was conducted at the population level using software RevMan 5.3 (Computer program, version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) and Prism 9.3.1 (GraphPad Software).

Na excretions were converted into mmol/d for consistency, using the following equations: 1 mmol Na = 23 mg Na and 1 mg Na = 2·54 mg salt[1]. Spearman correlation coefficients were converted to Pearson correlation coefficients for consistency using the following equations: $r = 2 \times \sin(r_s \times \pi/6)$[22]. Correlation coefficients (r) reported in each study were converted into Fisher's Z using the following specific formula[23]. The conversion formula between the correlation coefficient and Fisher's Z is as follows: $Z = 0.5 \times [\ln(1 + r) – \ln(1–r)]$. The variance of Z is: $Vz = 1/(n–3)$. The standard error of Z is: $SEz = \sqrt{Vz}$.

Quality assessment

Study quality was independently assessed by two reviewers (ZQ, ST) using a modified tool for evaluating dietary intake validation studies[24]. The tool rates the studies through five domains on a scale from 0 (poorest quality) to 7 (highest quality), with the following interpretations: excellent if the score ≥5·0; good if ≥3·5 and <5·0; acceptable or reasonable if ≥2·5 and <3·0; and poor if <2·5.

The quality assessment domain was modified to facilitate the estimated 24hUNa by spot urine[1], through the consideration of variables as below: (1) sample, with a maximum of 1 point: 0·5 point when the sample size was of more than 100 individuals; and 0·5 point allocated when the sample was homogeneous for sex, age and population; otherwise, sample was considered non-homogeneous and given a score of 0; (2) statistics. A maximum of 3 points was allocated; 1 for MD between estimated and measured
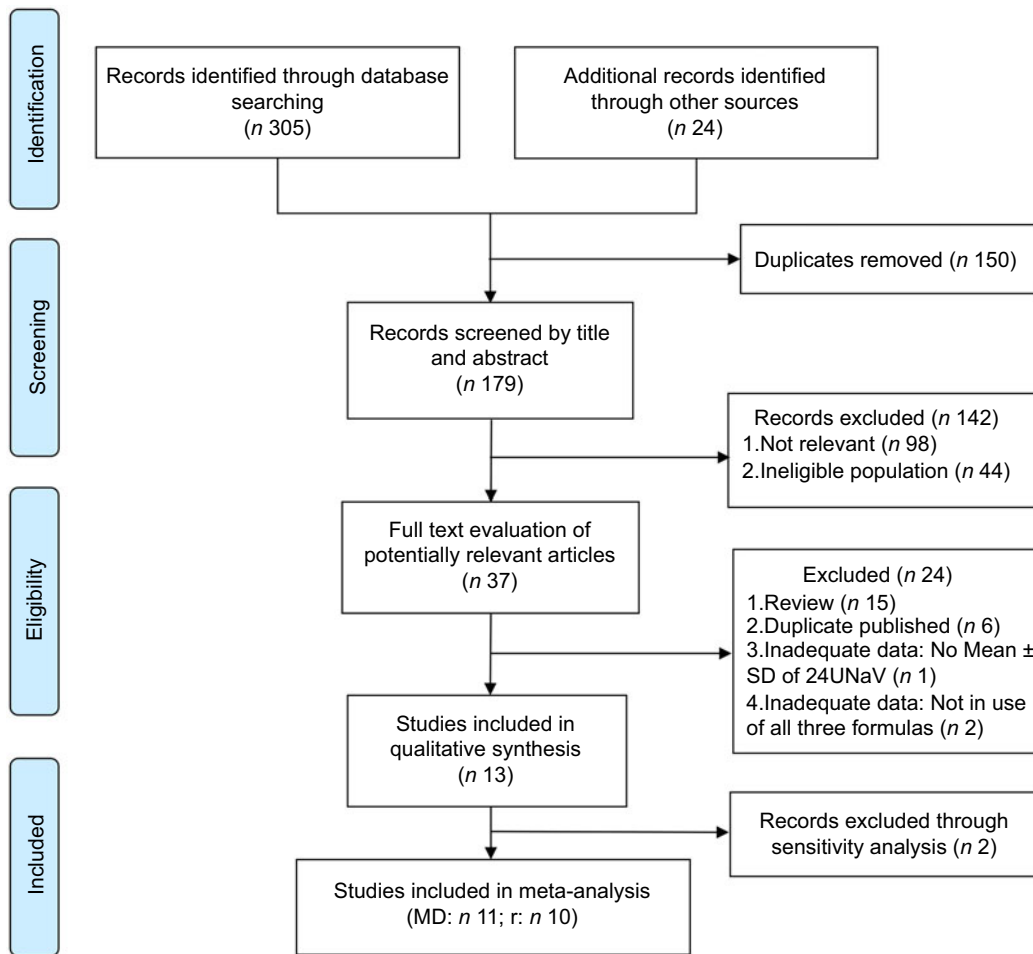
Fig. 1 PRISMA flow diagram of the screening procedure followed to identify eligible studies. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; MD, mean difference; r, correlation coefficient

values; 0·5–1 point according to the correlation used (r, ICC); 0·5–1 according to the agreement used Bland–Altman plots or rate of misclassification. (3) Data collection with a maximum of 1 point: 0·5 point if verbal or written instructions were conducted to collect urine to the participants; plus 0·5 when spillage or missed voids were assessed post-collection. (4) Seasonality. Addition of 0·5 point only when considered in the validation design. (5) Supplements. Addition of 1·5 points when the validation study considered supplements. The results of quality assessment are shown in Table 2.

Results

Literature selection

One hundred seventy-nine articles were retrieved initially, of which 142 articles were excluded, leaving thirty-seven studies for full-text review. Finally, thirteen studies were included in this review, and eleven studies were conducted in the meta-analysis. The study selection process is presented in Fig. 1.

Study characteristics

Through literature selection, thirteen studies involving 8369 participants from fifteen provinces of China (Beijing[19,25], Shanghai[19], Tianjin[19], Sichuan[19,26], Shandong[19,27], Henan[19], Xinjiang[19], Gansu[19], Zhejiang[14,15], Jiangxi[28], Hunan[16], Shanxi[29,30], Dalian[18], Ningxia[17], Shaanxi[13]) were initially included. Among all included studies, six (46·15 %) were conducted in the healthy population[14–16,26–28], seven (53·85 %) included the high-risk population, five (38·46 %) were associated with the hypertensive patients[12,17,18,26,29] and two (15·38 %) involved the stroke high-risk population[13,30]. Twelve studies (92·31 %) recruited adults, while one focused on adolescents[16]. The detailed characteristics of included thirteen studies are presented in Table 1.

Quality assessment

All included studies were of good quality, with three studies rated as excellent and the others as good. The details are presented in Table 2.

Table 1 Characteristics of included studies

First author, year	Area studied	Population studied	Mean age (years)	Sample size	Female proportion	Measured 24hUNa (mmol/d)		Fasting	Urine type	Kawasaki 24hUNa (mmol/d)		r	Tanaka 24hUNa (mmol/d)		r	INTERSALT 24hUNa (mmol/d)		r
Xiaofu Du 2021[15]	Zhejiang	Healthy adults	46·7	1424	51·1 %	165·7	71·5	Yes	MU	183·8	56·7	0·3	142·9	35·6	0·3	133·6	33·7	0·3
Jianwei Xu 2020[14]	Zhejiang	Healthy adults	46·7	1428	50·9 %	167·2	74·7	Yes	MU	184·1	56·9	0·4	143·1	35·6	0·3	133·8	33·9	0·4
Jianwei Xu 2020[27]	Shandong	Healthy adults	43·8	1671	50·0 %	176·4	79·1	Yes	MU	235·0	70·7	0·4	173·8	41·1	0·4	152·0	36·5	0·4
Long Zhou 2017[28]	Jiangxi	Healthy adults	51·1	141	94·3 %	220·8	78·5	N/A	MU	246·1	66·8	0·3*	143·6	24·7	0·4*	183·7	39·0	0·2*
Ying Zhang 2018[25]	Beijing	Healthy adults	32·2	85	62·4 %	198·2	83·0	N/A	SMU, CU	231·6	67·7	0·3*	193·93	50·2	0·5*	136·5	29·9	0·4*
Jie Dong 2019[16]	Hunan	Healthy adolescents	12·1	284	47·9 %	124·9	42·5	Yes	MU	195·0	48·6	0·2	124·3	24·9	0·6	115·6	31·3	0·3
Xin Zhang 2021[26]	Sichuan	General Tibetan adults (hypertension 54·5 %)	51·2	323	60·9 %	198·8	38·7	Yes	SMU	204·2	47·5	0·4	158·0	29·6	0·4	141·7	33·3	0·3
Yaguang Peng 2016[29]	Shanxi	General adults (hypertension 56·9 %)	53·2	116	68·1 %	275·8	107·4	Yes	MU	243·6	64·0	0·2	175·6	33·6	0·3	154·2	38·0	0·2
Ni Qian 2021[18]	Dalian	Hypertensive patients	55·6	1154	46·0 %	129·1	54·8	N/A	MU	213·9	65·7	N/A	167·4	40·4	N/A	142·6	38·7	N/A
Yan Sun 2020[19]	8 provinces	Hypertensive patients	60·0	290	53·4 %	145·7	66·7	NO	CU	216·4	68·7	0·6	169·4	41·9	0·6	137·81	40·1	0·5
Beike Wu 2022[30]	Shanxi	Stroke patients	64·8	281	49·5 %	180·7	67·6	NO	CU	218·7	70·5	0·4	169·3	41·6	0·4	142·86	44·6	0·4
Wenxia Ma 2017[13]	Shaanxi	High-risk elder patients of stroke	67·5	365	57·5 %	162·0	70·4	NO	CU	193·9	70·7	0·4	378·7	109·9	0·4	130·0	41·5	0·3
Yi Zhao 2019[17]	Ningxia	Hypertensive patients	69·8	807	42·5 %	131·7	66·1	NO	CU	1906·5	726·5	N/A	927·0	270·0	N/A	128·7	49·1	N/A

24hUNa, 24-h urinary Na; MU, morning urine; SMU, second morning urine; CU, casual spot urine; r, Pearson correlation coefficient between measured and formula-based estimated 24hUNa excretion, except for Spearman correlation efficient with *; N/A, no statistic.

Table 2 Quality assessment of the included studies

| Domain	Specific item	Xiaofu Du 2021[15]	Jianwei Xu 2020[14]	Jianwei Xu 2020[27]	Long Zhou 2017[28]	Ying Zhang 2018[25]	Jie Dong 2019[16]	Xin Zhang 2021[26]	Yaguang Peng 2016[29]	NiQian 2021[18]	Yan Sun 2020[19]	Beike Wu2022[30]	Wenxia Ma 2017[13]	YiZhao 2019[17]
Sample	$N > 100$	0·5	0·5	0·5	0·5	0	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5
	Non-homogenous sample (sex, age, population)	0·5	0·5	0·5	0	0·5	0	0·5	0·5	0	0	0	0	0
Statistics	Mean difference	1	1	1	1	1	1	1	1	1	1	1	1	1
	Correlation	1	1	1	0·5	0·5	1	1	1	0·5	0·5	1	1	0·5
	Agreement	1	0·5	1	1	1	1	1	0·5	1	1	1	0·5	0·5
Data collection	Verbal or written instructions to collect urine to the participants	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5
	Spillage or missed voids assessed post-collection	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5
Seasonality	Considered	0	0	0	0	0	0	0	0	0	0	0	0	0
Supplements	Included and data considered in analysis	0	0	0	0	0	0	0	0	0	0	0	0	0
Score*		5	4·5	5	4	4	4·5	5	4·5	4	4	4·5	4	3·5
Quality†		E	G	E	G	G	G	E	G	G	G	G	G	G

*Score interpretations: ≥5·0, excellent quality; ≥3·5 and <5·0, good quality; ≥2·5 and <3·5, acceptable quality; <2·5, poor quality.
†E, excellent; G, good.

Table 3 Sensitivity analyses of mean difference (MD) in different formulas

Formula		Min of MD	Max of MD	Pooled MD
Kawasaki	Sensitivity 1	−2·10	1774·80	155·74
	n 13, $I^2 = 100\%$	−9·55, 5·35	1724·47, 1825·13	111·32, 200·15
	Sensitivity 2	−2·10	84·80	32·79
	n 12, $I^2 = 99\%$	−9·55, 5·35	79·86, 89·76	13·95, 51·63
	Sensitivity 3	5·40	84·80	36·07
	n 11, $I^2 = 99\%$	−1·28, 12·08	79·86, 89·76	16·89, 55·25
Tanaka	Sensitivity 1	−0·60	795·30	60·16
	n 13, $I^2 = 100\%$	−6·33, 5·13	776·12, 814·48	12·46, 107·86
	Sensitivity 2	−0·60	216·70	−0·45
	n 12, $I^2 = 99\%$	−6·33, 5·13	203·31, 230·09	−24·68, 23·79
	Sensitivity 3	−0·60	−100·20	−19·62
	n 11, $I^2 = 99\%$	−6·33, 5·13	−120·68, −79·72	−37·37, −1·87
INTERSALT	Sensitivity 1	−3·00	−121·60	−32·79
	n 13, $I^2 = 100\%$	−8·68, 2·68	−142·33, −100·87	−45·96, −19·61
	Sensitivity 2	−7·85	−121·60	−35·41
	n 12, $I^2 = 98\%$	−16·80, 1·10	−142·33, −100·87	−49·41, −21·40
	Sensitivity 3	−7·85	−121·60	−35·78
	n 11, $I^2 = 99\%$	−16·80, 1·10	−142·33, −100·87	−50·76, −20·80

Sensitivity 1, including all available thirteen studies; Sensitivity 2, excluded one study[17] that had a large impact on the overall results from thirteen studies; Sensitivity 3, excluded two studies[13,17] that had large impacts on the overall results from thirteen studies.
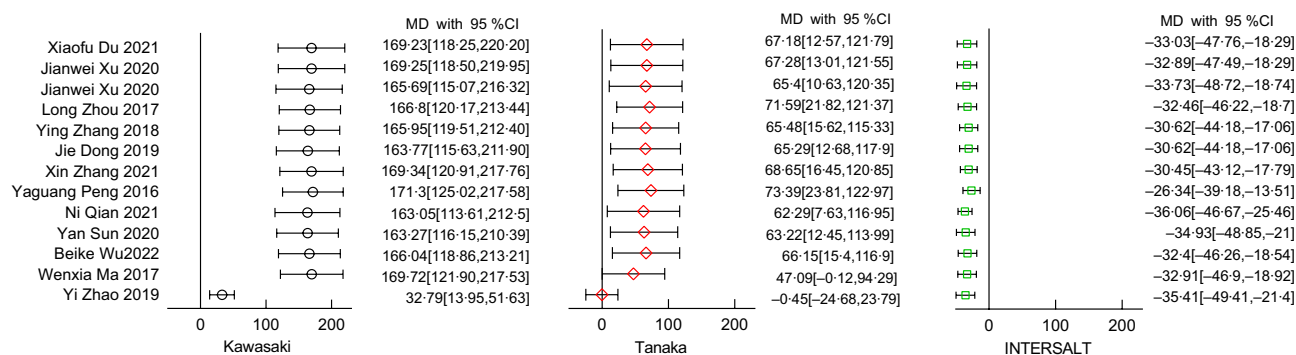
Fig. 2 Sensitivity analyses in use of the 'leave-one-out' method: pooled estimates were from random-effects models with removing one study at a time

Sensitivity analyses

As shown in Fig. 2, sensitivity analysis using the 'leave-one-out' approach excluded Yi Zhao *et al.*'s study[17] and Wenxia Ma *et al.*'s study[13] which had great impact on the robustness of the overall results. Table 3 shows the impact of the two excluded studies on the meta-analysis.

Overall result

The final meta-analysis as shown in Fig. 3, which included eleven studies and 7197 participants, observed a MD of 36·07 mmol/d (95 %CI: 16·89, 55·25) in the Kawasaki formula, −19·62 mmol/d (95 %CI −37·37, −1·87) in the Tanaka formula, and −35·78 mmol/d (95 %CI −50·76, −20·80) in the INTERSALT formula. Of the eleven included studies, ten (90·90 %) provided correlation coefficients between the estimates and the measures. The meta-analysis (Fig. 4) showed a pooled r-Fisher's Z of 0·43 (95 %CI 0·37, 0·49) in the Tanaka formula, 0·39 (95 %CI 0·32, 0·45) in the Kawasaki formula and 0·36 (95 %CI 0·31, 0·42) in the INTERSALT formula. According to the

interpretation of the correlation coefficients from Psychology[31], the correlation coefficient converted from r-Fisher's Z showed that the Tanaka formula (0·41) performed a moderate correlation, while the Kawasaki formula (0·37) and the INTERSALT formula (0·35) performed a weak correlation. Through the comparison of the statistical significance of the difference between two independent correlation coefficients, the Tanaka formula had a higher correlation than the Kawasaki formula (0·41 *v.* 0·37, *P* = 0·01) and the INTERSALT formula (0·41 *v.* 0·35, *P* < 0·01).

Subgroup analysis

For those consuming over 10 g/d, the Kawasaki formula indicated a MD of 22·14 mmol/d (95 % CI −3·97, 48·25), while the Tanaka and INTERSALT formulas showed −38·73 mmol/d (95 % CI −63·33, −14·13) and −55·02 mmol/d (95 % CI −74·62, −35·41), respectively. In contrast, among participants with an intake of 10 g/d or less, the Kawasaki formula revealed a MD of 53·11 mmol/d (95 % CI 27·84,

Study or Subgroup	Estimated Mean	SD	Total	Measured Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 Kawasaki								
Xiaofu Du 2021	183.8	56.7	1424	165.7	71.5	1424	9.4%	18.10 [13.36, 22.84]
Jianwei Xu 2019	184.1	56.8	1428	167.2	74.7	1428	9.4%	16.90 [12.03, 21.77]
Jianwei Xu 2020	235	70.7	1671	176.4	79.1	1671	9.4%	58.60 [53.51, 63.69]
Long Zhou 2017	246.1	66.8	141	220.8	78.5	141	8.8%	25.30 [8.29, 42.31]
Ying Zhang 2018	231.59	67.66	85	198.18	82.99	85	8.3%	33.41 [10.65, 56.17]
Jie Dong 2019	195	48.6	284	124.9	42.5	284	9.3%	70.10 [62.59, 77.61]
Xin Zhang 2021	204.2	47.5	323	198.8	38.7	323	9.3%	5.40 [−1.28, 12.08]
Yaguang Peng 2016	243.6	64	116	275.8	107.4	116	8.3%	−32.20 [−54.95, −9.45]
Ni Qian 2021	213.9	65.7	1154	129.1	54.8	1154	9.4%	84.80 [79.86, 89.74]
Yan Sun 2020	216.41	68.66	290	145.66	66.67	290	9.2%	70.75 [59.74, 81.76]
Beike Wu 2022	218.68	70.48	281	180.66	67.61	281	9.1%	38.02 [26.60, 49.44]
Subtotal (95% CI)			7197			7197	100.0%	36.07 [16.89, 55.25]

Heterogeneity: Tau² = 1013.00; Chi² = 770.31, df = 10 (P < 0.00001); I² = 99%
Test for overall effect: Z = 3.69 (P = 0.0002)

Study or Subgroup	Estimated Mean	SD	Total	Measured Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.1.2 Tanaka								
Xiaofu Du 2021	142.9	35.6	1424	165.7	71.5	1424	9.4%	−22.80 [−26.95, −18.65]
Jianwei Xu 2019	143.1	35.6	1428	167.2	74.7	1428	9.4%	−24.10 [−28.39, −19.81]
Jianwei Xu 2020	173.8	41.1	1671	176.4	79.1	1671	9.4%	−2.60 [−6.87, 1.67]
Long Zhou 2017	143.6	24.7	141	220.8	78.5	141	8.9%	−77.20 [−90.78, −63.62]
Ying Zhang 2018	193.93	50.17	85	198.18	82.99	85	8.3%	−4.25 [−24.87, 16.37]
Jie Dong 2019	124.3	24.9	284	124.9	42.5	284	9.3%	−0.60 [−6.33, 5.13]
Xin Zhang 2021	158	29.6	323	198.8	38.7	323	9.3%	−40.80 [−46.11, −35.49]
Yaguang Peng 2016	175.6	33.6	116	275.8	107.4	116	8.4%	−100.20 [−120.68, −79.72]
Ni Qian 2021	164.7	40.4	1154	129.1	54.8	1154	9.4%	35.60 [31.67, 39.53]
Yan Sun 2020	169.4	41.86	290	145.66	66.67	290	9.2%	23.74 [14.68, 32.80]
Beike Wu 2022	169.33	41.62	281	180.66	67.61	281	9.2%	−11.33 [−20.61, −2.05]
Subtotal (95% CI)			7197			7197	100.0%	−19.62 [−37.37, −1.87]

Heterogeneity: Tau² = 872.35; Chi² = 959.95, df = 10 (P < 0.00001); I² = 99%
Test for overall effect: Z = 2.17 (P = 0.03)

Study or Subgroup	Estimated Mean	SD	Total	Measured Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.1.3 INTERSALT								
Xiaofu Du 2021	133.6	33.7	1424	165.7	71.5	1424	9.4%	−32.10 [−36.21, −27.99]
Jianwei Xu 2019	133.8	33.9	1428	167.2	74.7	1428	9.4%	−33.40 [−37.65, −29.15]
Jianwei Xu 2020	152	36.5	1671	176.4	79.1	1671	9.4%	−24.40 [−28.58, −20.22]
Long Zhou 2017	183.7	39	141	220.8	78.5	141	8.7%	−37.10 [−51.57, −22.63]
Ying Zhang 2018	136.47	29.91	85	198.18	82.99	85	8.3%	−61.71 [−80.46, −42.96]
Jie Dong 2019	115.6	31.3	284	124.9	42.5	284	9.4%	−9.30 [−15.44, −3.16]
Xin Zhang 2021	141.7	33.3	323	198.8	38.7	323	9.4%	−57.10 [−62.67, −51.53]
Yaguang Peng 2016	154.2	38	116	275.8	107.4	116	8.0%	−121.60 [−142.33, −100.87]
Ni Qian 2021	142.6	38.7	1154	129.1	54.8	1154	9.5%	13.50 [9.63, 17.37]
Yan Sun 2020	137.81	40.11	290	145.66	66.67	290	9.2%	−7.85 [−16.80, 1.10]
Beike Wu 2022	142.86	44.64	281	180.66	67.61	281	9.2%	−37.80 [−47.27, −28.33]
Subtotal (95% CI)			7197			7197	100.0%	−35.78 [−50.76, −20.80]

Heterogeneity: Tau² = 614.15; Chi² = 674.18, df = 10 (P < 0.00001); I² = 99%
Test for overall effect: Z = 4.68 (P < 0.00001)

Test for subgroup differences: Chi² = 34.53, df = 2 (P < 0.00001), I² = 94.2%
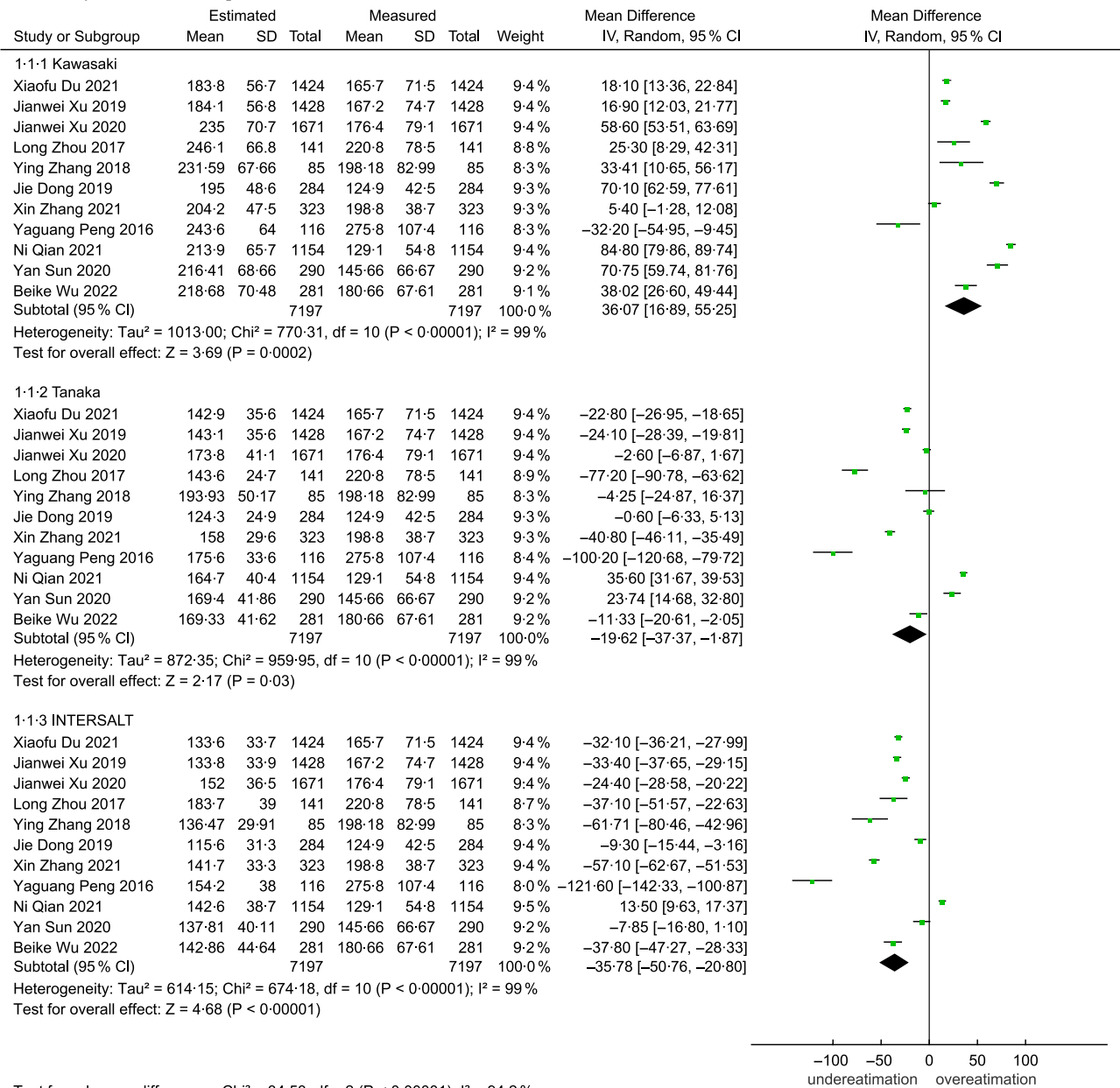

Fig. 3 Forest plot of mean difference (MD) between measures and estimates from different formulas

78.37); for the same group, the Tanaka and INTERSALT formulas reported 2.30 mmol/d (95% CI -24.06, 28.66) and −13.87 mmol/d (95% CI −34.49, 6.76), respectively. Examining the casual spot urine group, MD of 54.42 mmol/d (95% CI 22.35, 86.50) was observed for the Kawasaki formula, 6.22 mmol/d (95% CI −28.15, 40.59) for the Tanaka formula and −34.81 mmol/d (95% CI −62.67, −6.96) for the INTERSALT formula. Meanwhile, in the fasting morning urine group, the observed MD were 24.17 mmol/d (95% CI 2.42, 45.93) using the Kawasaki formula, −28.96 mmol/d (95% CI −43.57, 14.35) with the Tanaka formula and −42.96 mmol/d (95% CI −57.25, −28.67) with the INTERSALT formula.

The detailed results are summarised in Fig. 5.

Discussion

Using spot urine samples could be a convenient alternative to 24-h urine collections for monitoring Na intake at the population level[26,32]. The three formulas in the meta-analyses all showed moderate correlations (0.36–0.43) between the estimated and measured 24hUNa, slightly lower than those observed in the Italian population (0.62–0.70)[33] and slightly higher than the Portuguese population (0.25–0.36)[34]. In a diverse population from eleven countries[35], the Kawasaki formula was considered a reliable alternative for estimating 24hUNa while the INTERSALT formula was seen as an acceptable alternative for monitoring Na intake/excretion in the French
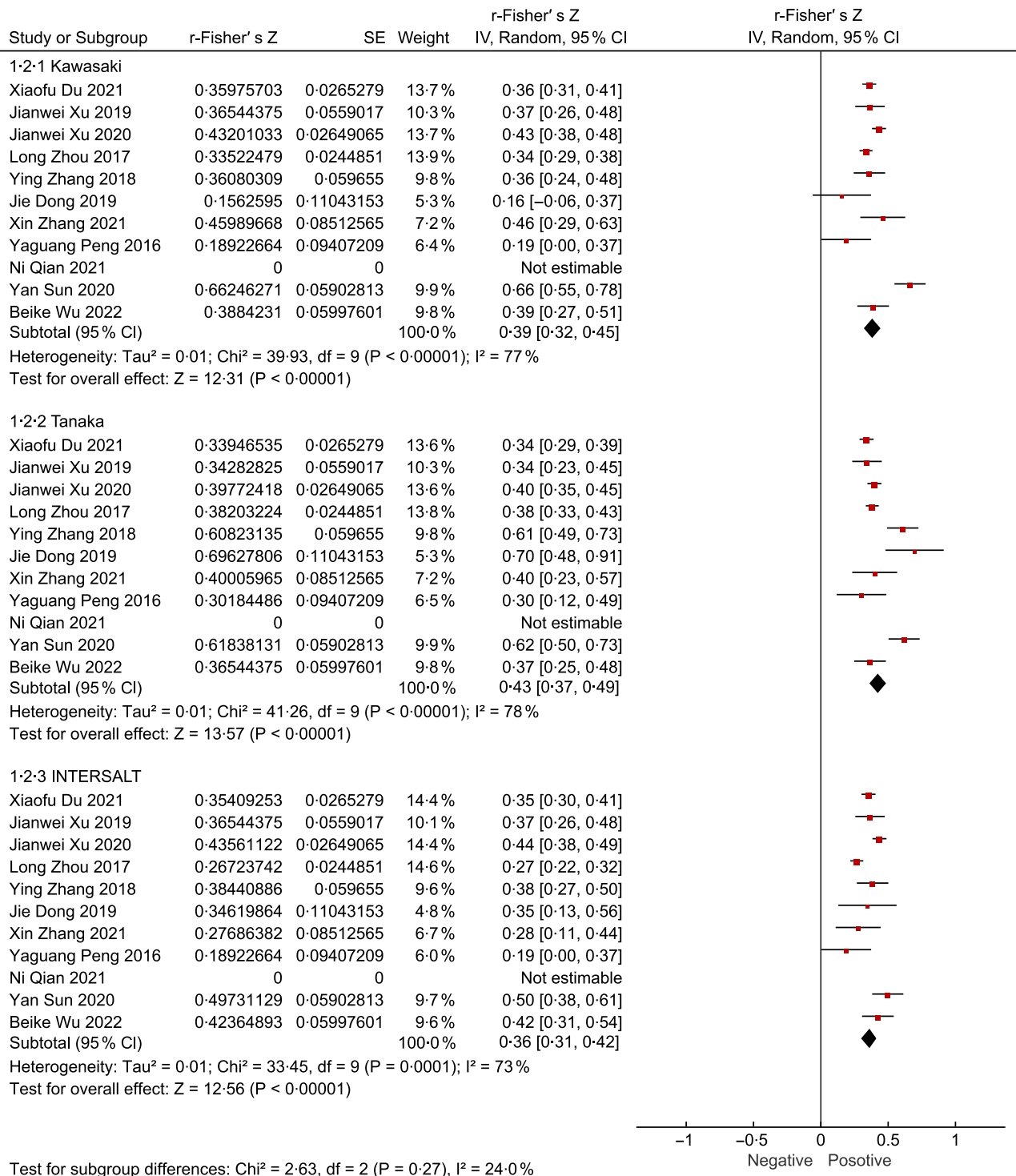
Fig. 4 Forest plot of correlation (r) between measures and estimates from different formulas

population[36]. Several foreign validation studies[37,38] also identified that the INTERSALT formula which derived from data across fifty-two centres in thirty-two countries perform better under complex ethnic compositions. This meta-analysis in the Chinese population suggested the Tanaka formula showed a less bias (−19·62 mmol/d) compared with the Kawasaki formula (36·07 mmol/d) and the INTERSALT formula (−35·78 mmol/d).

Subgroup analysis identified two key factors that might influence the accuracy of formula estimates. First, Na excretion exhibited a diurnal variation[39], implying that the time of urine sample collection could impact the overestimation or underestimation of 24-hour urinary sodium excretion (24hUNa)[40,41]. The Kawasaki formula initially was established based on fasting second morning urine specimens[9], which had a lower Na concentration[27,42],
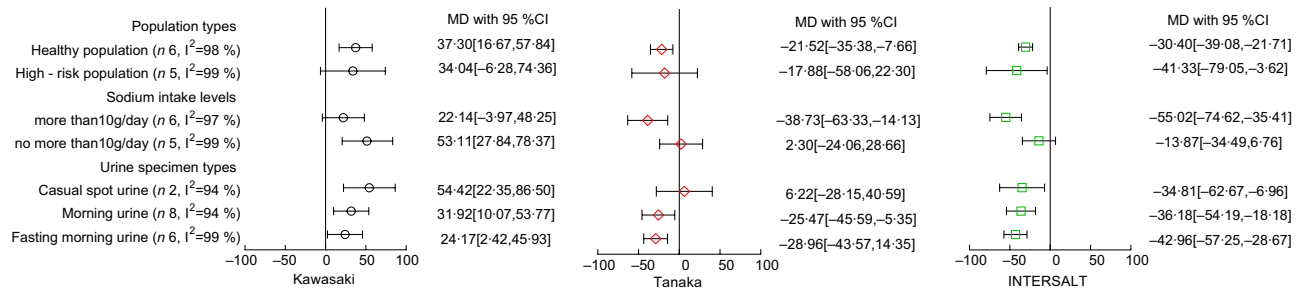
Fig. 5 Forest plot of mean difference (MD) from different formulas in different subgroups

while the Tanaka formula and the INTERSALT formula were established based on casual spot urine specimens which took the daily change of urine Na into account. Therefore, the Kawasaki formula produced higher estimates when collecting casual spot urine specimens, and the Tanaka and the INTERSALT formula produced lower estimates when fasting morning urine was collected. Second the level of Na intake appears to play a role in estimation accuracy. Numerous studies[12,18,19,29,39,42] have demonstrated that prediction formulas are more likely to overestimate in populations with lower salt intake and underestimate in those with higher intake. This was consistent with the trends presented in the subgroups of urinary Na intake levels.

The 24hUNa estimates by the Kawasaki formula tended to be overestimated, while those by the Tanaka and INTERSALT formulas were inclined to be underestimated, consistent with trends identified in Brazilian[43], Iranian[33] and Indian populations[37]. More accurate estimation results might be achieved by closely approximating the conditions under which the formula was established. Therefore, the estimates derived from the Kawasaki formula in fasting morning urine group (24·17 mmol/d) and in the group with salt intake group over 10 g/d (22·14 mmol/d) are more accurate compared with those obtained by the other two formulas.

Among the studies excluded from the sensitivity analysis, one focused on the elderly high-risk stroke population in rural area of Shaanxi province, and the other on elderly hypertensive patients in a rural area of the Ningxia Hui Autonomous Region. Both studies involved high-risk elderly populations with lower urine volumes and higher urine Na concentrations, resulting in significantly higher estimates compared with the measures. Although these two studies were not included in the final meta-analysis, there is a need to validate more accurate formulas in more diverse populations or in larger epidemiological studies within China.

There were two limitations in this study. First, the meta-analysis mainly evaluated the validity of the Kawasaki formula, the Tanaka formula and the INTERSALT formula, involving only 8369 participants from thirteen studies in fifteen provinces of China, which might limit its extrapolation. Second, correlation might not be the best measure to assess the validity in the current context of monitoring and evaluating public health programmes for population salt reduction[44]. A more comprehensive and in-depth evaluation of different formulas should be implemented in the future.

Conclusion

The meta-analysis suggested that the Tanaka formula estimates exhibited less bias and higher correlation in the Chinese population. The time of collecting spot urine specimens and Na intake level of the sample population might be the main factors affecting the accuracy of the formula estimation.

Conflict of interest

There are no conflicts of interest.

Authorship

ZQ, BW and ZL conceived the study. ZQ, ST and HY conducted the screening of studies and quality assessment. ZQ analysed the data, with support from ST, YL, HY and KW. ST, BW, YL, KW, HY and ZL reviewed and provided comments on the subsequent versions of the paper. All authors approved the final version of the manuscript.

Ethics of human subject participation

Not applicable.

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