International Journal of Epidemiology, 2016, 239–250
doi: 10.1093/ije/dyv313
Advance Access Publication Date: 21 January 2016
Original article

Miscellaneous

Mean population salt intake estimated from 24-h urine samples and spot urine samples: a systematic review and meta-analysis

Liping Huang,[1] Michelle Crino,[1] Jason HY Wu,[1] Mark Woodward,[1,2,3,4] Federica Barzi,[1] Mary-Anne Land,[1] Rachael McLean,[6] Jacqui Webster,[1] Batsaikhan Enkhtungalag[7] and Bruce Neal[1,4,5]*

[1]George Institute for Global Health, University of Sydney, Sydney, NSW, Australia, [2]George Institute for Global Health, University of Oxford, Oxford, UK, [3]Department of Epidemiology, Johns Hopkins University, Baltimore, MD, USA, [4]Department of Medicine, Royal Prince Alfred Hospital, Sydney, Australia, [5]Division of Epidemiology and Biostatistics, School of Public Health, Faculty of Medicine, Imperial College London, London, UK, [6]Departments of Preventive and Social Medicine/Human Nutrition, University of Otago, Dunedin, New Zealand, [7]National Center for Public Health, Bayanzurkh district, Ulaanbaatar, Mongolia

*Corresponding author. The George Institute for Global Health Australia, Level 10, King George V Building, 83-117 Missenden Rd, Camperdown, NSW 2050, Australia. E-mail: bneal@georgeinstitute.org.au

Accepted 28 October 2015

Abstract

Background: Estimating equations based on spot urine samples have been identified as a possible alternative approach to 24-h urine collections for determining mean population salt intake. This review compares estimates of mean population salt intake based upon spot and 24-h urine samples.

Methods: We systematically searched for all studies that reported estimates of daily salt intake based upon both spot and 24-h urine samples for the same population. The associations between the two were quantified and compared overall and in subsets of studies.

Results: A total of 538 records were identified, 108 were assessed as full text and 29 were included. The included studies involved 10 414 participants from 34 countries and made 71 comparisons available for the primary analysis. Overall average population salt intake estimated from 24-h urine samples was 9.3 g/day compared with 9.0 g/day estimated from the spot urine samples. Estimates based upon spot urine samples had excellent sensitivity (97%) and specificity (100%) at classifying mean population salt intake as above or below the World Health Organization maximum target of 5 g/day. Compared with the 24-h samples, estimates based upon spot urine overestimated intake at lower levels of consumption and underestimated intake at higher levels of consumption.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

© The Author 2016; all rights reserved. Published by Oxford University Press on behalf of the International Epidemiological Association

Conclusions: Estimates of mean population salt intake based upon spot urine samples can provide countries with a good indication of mean population salt intake and whether action on salt consumption is required.

Key words: Sodium, salt intake, 24-h urine collection, spot urine collection

Key messages

- Collection of spot urine samples is a plausible alternative to 24-h urine collection for estimating population salt intake.
- Parallel collection of 24-h urine samples in a subset of spot urine samples collection will be valuable, especially for defining the potential to use spot urine samples to track changes in salt intake over time.
- Compiling and analysing individual participant datasets from completed studies would likely provide valuable additional insight.

Background

The totality of the available evidence suggests that excess intake of salt contributes to a large proportion of deaths from cardiovascular diseases[1,2] and that reductions in population salt intake have the potential to deliver large population health gains at low cost.[3] The World Health Organization (WHO) has identified 5 g/day as a maximum target for daily salt intake.[4] Further, in response to the 2011 United Nations high-level meeting on the prevention and control of non-communicable diseases, the WHO has recommended that all Member States reduce population salt intake by 30% by 2025.[5] For a country to address these objectives requires an estimate of mean national salt intake and, in December 2013, the WHO incorporated measurement of mean population salt intake as an element of the WHO STEPwise approach to Surveillance (STEPS) protocol.[6]

The standard approach to measuring the mean salt intake of a population has been the collection of 24-h urine samples on a subset of individuals.[7] However, this method is costly and confers a significant participant burden which usually results in a low participation rate.[8] Estimates based upon 24-h urine samples are also not an exact measure of salt intake because some sodium is excreted through non-urinary routes[9] and some dietary sodium derives from sources other than salt. A number of Member States have indicated to the WHO that large-scale repeated 24-h urine collections are impractical.[10] Equations that use spot urine samples to estimate population salt intake have been explored as a possible alternative in a number of studies.[11–18]. Spot urine samples have the advantage that they are easier and cheaper to collect, and this method has been used to replace 24-h urine collections to estimate exposure to pesticides[19,20] and also to assess dietary iodine intake.[21] The key weakness is that urinary sodium excretion is known to vary throughout the day[22] and the use of spot urine samples may introduce additional random and systematic errors.

It is important to note that the current standard approach based upon a single 24-h urine collection is by no means a 'gold standard' method for estimating salt intake, because some salt is excreted through faeces and sweat[9] and under-collection of urine is commonly reported.[23] Furthermore, salt intake and excretion are known to vary from day to day as well as throughout the day, and multiple 24-h urine collections are required to estimate an individual's true usual salt consumption.[24]

The objective of this systematic review was to quantify the differences in the estimates of mean population salt intake obtained using 24-h compared with spot urine samples and to identify factors influencing the validity of the estimates obtained using spot urine samples.

Methods

Search strategy

The electronic databases MEDLINE, PreMEDLINE, EMBASE, GLOBAL HEALTH and the COCHRANE LIBRARY were searched using applicable terms (Appendix A, available as Supplementary data at *IJE* online) in June 2015. A keyword search was also conducted in the China National Knowledge Infrastructure (CNKI) database. Two authors (L.H. and M.C.) independently screened all titles and abstracts identified by these searches, and potentially eligible articles were obtained in full text. These full-text papers were then reviewed by both authors (except two published in Chinese that were only reviewed by L.H.) to determine eligibility, with disagreements settled by discussion between the two. Hand searches of the reference lists of included studies

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

were then done and enquiries were made with academic colleagues working in the field to identify any other studies with data.

Study inclusion criteria

Studies were eligible for inclusion if they were done in adult humans, were available in full text and reported estimated mean population salt intake derived both from 24-h and spot urine samples. In addition, a standard deviation (SD) about each intake estimate had to be available or able to be estimated. There were no restrictions on language, study sample size or characteristics of the study population. Studies that provided only a correlation coefficient between salt intake estimates for individuals derived from 24-h and spot urine samples were not included, as these data did not enable the study objectives to be addressed. Studies were, however, included in the absence of explicit reporting of daily salt intake from spot urine samples so long as estimates could be obtained using data reported in the paper.[14,25–41] Studies that collected urine samples over multiple days were included with the average value based upon all available estimates used for the analyses.[29–33,37,41]

Data extraction

Standard data were extracted independently and in duplicate to a spreadsheet (Appendix Table 3, available as Supplementary data at *IJE* online). The data included first author, year of publication, population studied, population characteristics, mean age / age range, proportion female, sample size, spot urine sample collection details (including sample timing where available), whether spot urine was part of (or separate from) the 24-h urine collection, the equation(s) used to estimate 24-h salt excretion from the spot urine sample (INTERSALT,[11] TANAKA,[15] KAWASAKI,[13] by rate or by concentration) and the mean population salt intake estimates (with measures of SD) obtained from the 24-h and spot urine samples. Where available, data were also extracted separately for men and women. Where data were only reported separately for participant subsets, these were pooled to obtain summary estimates for the entire population for the primary analysis. Countries were defined as 'developed' or 'developing' based on World Bank classifications.[42]

Data were extracted from 29 studies. The estimates derived from the 24-h urine samples were all based upon 24-h urine collections for which the sodium concentration of the urine was known along with the volume. By contrast, the estimates made from the spot urine samples were derived in multiple different ways. One or more of three previously reported equations (INTERSALT,[11,18,43–46] TANAKA[15,18,43–47] and KAWASAKI[18,43–47]) were used to impute mean daily salt intake based on the spot urine sodium concentration for multiple studies. For studies where no equation had been employed, we used other methods to estimate the mean population daily salt intake based upon the spot urine data. For 12 studies there was a measure of the mean sodium excretion in spot urine collections of known mean duration or there was a measure of hourly sodium excretion rate determined from a 24-h urine sample and from a spot urine sample. For these studies, an estimate of daily salt intake was obtained from the spot urine samples by inflating the excretion values to a 24-h equivalent[25–35,39] (henceforth described as estimation 'by rate'). For six other studies an estimate of the mean concentration of sodium in a spot urine sample was available along with the 24-h urine volume. For these studies, a mean daily salt intake estimate was obtained by multiplying the mean concentration of sodium in the spot urine by the mean 24-h urine volume[36–38,40,41] (henceforth described as estimation by concentration). Salt consumption data were expressed in grams of salt (sodium chloride) using the following conversions: 1 mmol Na = 1 mEq Na = 23 mg Na, and 1 g Na = 2.54 g NaCl.

Outcomes

The primary outcomes were the sensitivity and specificity of spot urine compared with 24-h urine samples in estimating population salt intake as above or below the WHO maximum target of 5 g/day, along with the differences between the mean daily salt intake estimates derived from the 24-h and spot urine samples overall and for data subsets.

Statistical analysis

Several studies reported comparisons for multiple population groups and many reported multiple comparisons using the same set of data subdivided into different parts, or using different equations, to explore various aspects of the estimation process. Care was taken to ensure that a given analysis in this overview included each piece of data only once, although separate analyses addressing different questions might use the same data again. For studies that reported intake estimates from spot urine samples using multiple different equations, the primary analyses used the estimates based upon INTERSALT,[11] TANAKA,[15], by KAWASAKI,[13] by rate or by concentration, in that order of preference. Estimates for subgroups were reported where at least five data points were available.

The capacity of population estimates based upon spot urine samples to correctly classify the mean salt intake of a population as above or below the 5 g/day WHO maximum

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

target (as defined by the measures based on the 24-h samples) was assessed by calculating the sensitivity

$$\frac{\text{Salt}_{\text{spot}} > 5g/day \quad \text{Salt}_{24\text{hour}} > 5g/day}{\text{Salt}_{24\text{hour}} > 5g/day}$$

and specificity

$$\frac{\text{Salt}_{\text{spot}} < 5g/day \quad \text{Salt}_{24\text{hour}} < 5g/day}{\text{Salt}_{24\text{hour}} < 5g/day}.$$

The difference between the methods was assessed using the mean of the within-person differences in salt excretion estimated from the spot urine and the salt excretion measured by the 24-h urine. If not reported, the SD was calculated from the standard error (SE), imputed using reported percentiles

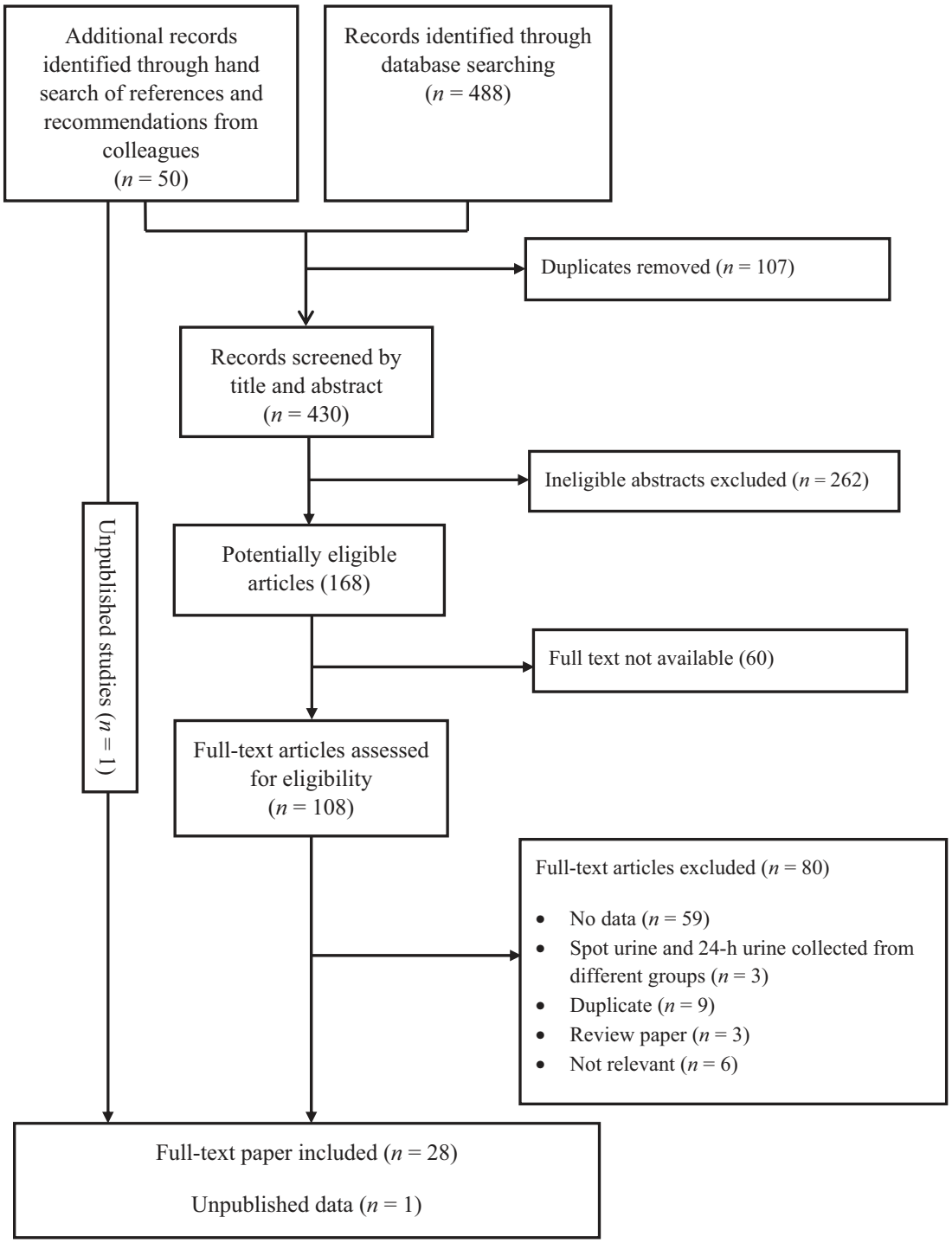

Figure 1. Flow diagram.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

Table 1. Characteristics of included studies and the 71 pairs of estimates of salt intake based on 24-h and spot urine samples used for the primary analysis

First author, year	Population studied	Age range or mean age (years)	Sample size	Proportion female	Equations used to estimate 24-h salt from spot urine[e]	Mean salt intake estimated from 24-h urine (SD)	Mean salt intake estimated from spot urine (SD)
Bankir L 2008	Seychelles	46±12	325	45%	Arithmetic[a]	6.0 (3.1)	8.8 (3.1)
Brown I 2013	Belgium, Charleroi	20-59	76	49%	INTERSALT	8.0 (2.0)	9.0 (2.0)
	Belgium, Ghent	20-59	96	50%	INTERSALT	8.3 (2.1)	8.8 (1.8)
	Denmark, Glostrup	20-59	96	50%	INTERSALT	8.1 (2.3)	8.6 (2.1)
	Finland, Joensuu	20-59	96	50%	INTERSALT	10.0 (2.4)	9.5 (2.1)
	Finland, Turku	20-59	96	50%	INTERSALT	9.1 (2.3)	9.0 (1.8)
	Germany, Bernried	20-59	95	49%	INTERSALT	10.2 (2.5)	9.2 (2.0)
	Germany, Cottbus	20-59	96	50%	INTERSALT	8.5 (2.7)	9.5 (2.0)
	Germany, Heidelberg	20-59	95	51%	INTERSALT	10.3 (2.5)	8.9 (2.0)
	Hungary, Porcsalma	20-59	96	50%	INTERSALT	11.5 (3.7)	11.3 (2.5)
	Iceland, Reykjavik	20-59	96	50%	INTERSALT	7.8 (1.9)	8.6 (1.9)
	Italy, Bassiano	20-59	95	51%	INTERSALT	10.9 (2.5)	11.5 (2.0)
	Italy, Gubbio	20-59	96	50%	INTERSALT	10.3 (2.3)	10.3 (1.9)
	Italy, Mirano	20-59	96	50%	INTERSALT	10.0 (2.2)	9.8 (1.9)
	Italy, Naples	20-59	96	50%	INTERSALT	9.5 (1.9)	9.9 (1.8)
	Malta, Dingli	20-59	96	50%	INTERSALT	10.1 (2.4)	10.1 (2.1)
	Netherlands, Zutphen	20-59	96	50%	INTERSALT	8.9 (2.3)	8.4 (2.0)
	Poland, Krakow	20-59	96	50%	INTERSALT	11.6 (3.5)	11.2 (2.4)
	Poland, Warsaw	20-59	96	50%	INTERSALT	11.2 (3.6)	10.5 (2.6)
	Portugal, Cartaxo	20-59	97	51%	INTERSALT	10.4 (3.0)	10.3 (2.0)
	Russia, Moscow	20-59	95	49%	INTERSALT	9.3 (2.2)	10.2 (2.2)
	Spain, Manresa	20-59	96	50%	INTERSALT	10.7 (2.7)	10.0 (2.2)
	Spain, Torrejon	20-59	96	50%	INTERSALT	10.2 (2.5)	10.2 (2.1)
	UK, Belfast	20-59	96	50%	INTERSALT	8.9 (2.0)	8.4 (1.9)
	UK, Birmingham	20-59	96	50%	INTERSALT	9.2 (1.7)	8.9 (1.5)
	UK, South Wales	20-59	96	50%	INTERSALT	9.2 (2.5)	9.2 (2.0)
	USA, Chicago	20-59	95	51%	INTERSALT	8.2 (2.6)	8.4 (2.0)
	USA, Hawaii	20-59	89	49%	INTERSALT	8.5 (2.4)	9.3 (2.4)
	USA, Jackson (Black)	20-59	88	55%	INTERSALT	8.3 (3.1)	8.5 (2.2)
	USA, Jackson (White)	20-59	96	50%	INTERSALT	8.4 (2.3)	8.0 (2.0)
Cogswell M 2013	USA , Washington DC (Black)	18-39	196	55%	INTERSALT	8.5 (3.7)	7.9 (2.1)
	USA, Washington DC (Other races)	18-39	210	54%	INTERSALT	8.3 (3.4)	7.5 (1.9)
Ding J 1983	China, Beijing	30-50	20	0%	Arithmetic[b]	12.9 (2.7)	10.7 (2.8)
Dyer A 1987	USA, Chicago, Minneapolis	41-80	107	37%	Arithmetic[b]	7.6 (3.7)	8.0 (4.0)
Dyer A 1987	USA	27-64	120	0%	Arithmetic[b]	9.8 (3.2)	9.1 (4.7)
Han W 2015	China, Beijing	58.4±14.5	222	55%	TANAKA	8.6 (3.6)	10.4 (3.4)
He J 1993	China, Liangshan (Rural)	19-55	30	0%	Arithmetic[c]	7.7 (4.3)	6.9 (4.3)
	China, Liangshan (Urban)	19-55	33	0%	Arithmetic[c]	10.4 (4.5)	8.4 (4.5)
Iwahori,T 2014	Japan, Osaka and Kyoto	39.9	48	48%	Arithmetic[c]	11.0 (5.3)	11.9 (6.1)

(Continued)

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

Table 1 Continued

First author, year	Population studied	Age range or mean age (years)	Sample size	Proportion female	Equations used to estimate 24-h salt from spot urine[e]	Mean salt intake estimated from 24-h urine (SD)	Mean salt intake estimated from spot urine (SD)
Jeffery P 2013	Australia (NSW,	20-88	381	56%	INTERSALT	8.5 (3.5)	8.4 (2.5)
	Victoria)	20-88	291	54%	INTERSALT	8.1 (3.4)	7.9 (2.2)
		20-88	276	56%	INTERSALT	7.9 (3.3)	7.9 (2.1)
Ji C 2013	Britain (White)	51	297	56%	TANAKA	8.8 (1.4)	8.8 (1.4)
	Britain (African Origin)	52	326	62%	TANAKA	9.1 (0.8)	9.1 (0.7)
	Britain (South Asians)	50	292	47%	TANAKA	8.6 (1.0)	8.6 (1.1)
Kang S 2012	Korea, Seoul	56±14	305	49%	Arithmetic[c]	9.9 (4.6)	10.3 (4.6)
Kara P 2013	Turkey, Van (normotensive)	49±5	21	71%	Arithmetic[b]	12.4 (6.2)	10.5 (5.9)
	Turkey, Van (hypertensive)	56±8	21	76%	Arithmetic[b]	10.7 (4.0)	11.1 (7.1)
Liu L 1986	China, Beijing	30-50	49	0%	Arithmetic[b]	14.3 (5.6)	12.1 (5.6)
Liu L 1987	China, Beijing	27-50	50	0%	Arithmetic[b]	14.7 (4.1)	13.6 (3.9)
Luft F 1983	USA, Indiana	22-62	8	33%	Arithmetic[b]	3.4 (0.4)	1.8 (0.1)
			8		Arithmetic[b]	6.4 (0.5)	3.8 (0.1)
			8		Arithmetic[b]	10.5 (0.6)	5.5 (0.3)
Luft F 1982	USA, (White)	19-54	22	40%	Arithmetic[b]	8.2 (0.9)	5.2 (0.8)
	USA, (Black)		21		Arithmetic[b]	8.1 (1.5)	4.8 (0.7)
Luft F 1982	USA, Indiana	19-32	*8	0%	Arithmetic[b]	3.1 (3.0)	1.4 (3.0)
			*8	0%	Arithmetic[b]	10.2 (3.5)	5.4 (3.5)
			*8	0%	Arithmetic[b]	18.7 (5.3)	10.8 (5.3)
Mann S 2010	USA, New York	>21	36	2%	Arithmetic[d]	9.4 (3.9)	10.6 (9.6)
			45		Arithmetic[d]	9.2 (5.4)	9.6 (8.3)
McLean R 2014	New Zealand, Dunedin	18-64	98	69%	INTERSALT	8.8 (4.1)	7.4 (1.8)
Mente A 2014	India, China, Colombia, Argentina, Brazil, Malaysia, South Africa, Turkey, Canada, Sweden, United Arab Emirates	56.6±9.4	1083	58%	INTERSALT	10.5 (5.0)	8.3 (2.2)
Mill J 2012	Brazil	30-74	109	54%	Arithmetic[b]	12 (4.1)	11.3 (4.9)
Pan W H 1994	China, Taiwan	24	30	48%	Arithmetic[b]	8.8 (3.0)	8.1 (3.5)
Rhee M-Y 2014	Korea	51±11	224	60%	INTERSALT	9.7 (3.8)	7.7 (1.8)
Subramanian S 2013	Singapore	53.5±15.2	333	49%	Arithmetic[c]	7.3 (4.0)	7.1 (4.6)
Toft U 2013	Denmark	28-74	473	78%	TANAKA	8.8 (5.5)	9.1 (2.6)
TANAKA T 2002	Japan, Tochigi, Osaka, Toyama	20-69	336	17%	TANAKA	10.4 (3.5)	9.0 (1.9)
Wolf J 1984	France	20-68	60	50%	Arithmetic[b]	8.3 (3.0)	11.0 (5.1)
			91	33%	Arithmetic[b]	8.6 (4.3)	18.6 (9.1)
Enkhtungalag B unpublished	Mongolia, Ulaanbaatar	25-64	1027	55%	INTERSALT	11.1 (5.9)	10.0 (2.0)

[a]Sodium concentration in spot urine*urine excretion rate in 24-h urine*24 h (grouped as using sodium concentration in spot urine*24 urine volume).

[b]Sodium excretion in spot urine / spot urine collection duration*24 h (grouped as sodium excretion rate in spot urine*24 h).

[c]Sodium concentration in spot urine*24-h sodium volume.

[d]Spot urine Na concentration / spot urine creatinine concentration*24-h creatinine content (grouped as sodium concentration in spot urine*24 urine volume).

[e]Several methods of estimating 24-h salt intake from spot urine samples were reported in the primary paper for some studies, but only the method used in the primary analysis is listed here.

*Method was unclear in the paper; equal number of participants was assumed in each level of salt intake.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

and assuming a standard normal distribution (for one study[16]), or by using the SD reported for the estimates from the 24-h samples for the estimates from the spot urine samples (for five studies[29,33,36–38]). The within-person variance in measured versus estimated differences (SD^2) was calculated as:[48]

$$\left(SD^2_{measured\ 24\ hour\ salt\ excretion}\right) + \left(SD^2_{spot\ urine\ estimated\ salt\ excretion}\right) - \left[2\ (r)\sqrt{SD^2_{measured\ 24\ hour\ salt\ excretion} \times SD^2_{spot\ urine\ estimated\ salt\ excretion}}\right]$$

r is the reported within-person correlation between the measured and estimated (from spot urine) salt excretion for each study and, if r was not available, it was imputed as 0.71 (the median of r among studies that reported this value).

Pooled summary estimates (salt excretion measured by 24-h urine, salt excretion estimated from spot urine and the difference between them) were calculated using DerSimonian and Laird inverse-variance weighted, random effects meta-analysis.[49] For these analyses, the variance (SE) of each study was calculated as SE = square root(SD^2/n). Random effects meta-regression was used to explore whether salt intake estimates were influenced by a series of pre-specified factors, with statistical significance assessed using permutation tests.[50] These factors comprised sex, the equation used (INTERSALT/TANAKA/KAWASAKI / by concentration / by rate), timing of spot urine collection (morning/evening/overnight/daytime/spot), ethnicity (Non-Asian countries / Asian countries), economic development (developed countries / developing countries) and whether the spot urine was a part of the 24-h urine sample (part/separate). Using meta-regression, we also assessed if the difference between measurement methods varied according to the level of salt excretion defined by the 24-h urine collection. All analyses were done using statistical package Stata V13.0. *P*-values less than 0.05 were deemed to indicate results that had likely not arisen by chance alone.

Results

The search identified 538 records, of which 168 were considered potentially eligible and 108 were reviewed in full text (Figure 1). Ultimately, data from 28 published reports were included[11,14–18,25–41,43–47] along with data from one unpublished study.[51] These studies included 10 414 participants recruited from 34 different countries reported between the years 1982 and 2015 (Appendix Table 3). Twelve of the studies were from European and North American countries; twelve from Asian countries; and one from each of the following countries: Australia, New Zealand, Brazil and the Seychelles Islands; and one with mixed populations. Participants ranged in age from 18 to 88 years, and 50% were female and made 71 comparisons available for primary analysis. The estimates included in the primary analysis derived from spot urine samples were variously made using the INTERSALT (38) and TANAKA (6) equations with a further 27 comparisons based upon a simple arithmetical method for estimation from the spot urine sample (Table 1). Overall, the mean salt intake was 9.3 g/day [95% confidence interval (CI): 9.0, 9.7) based upon the 24-h urine samples,

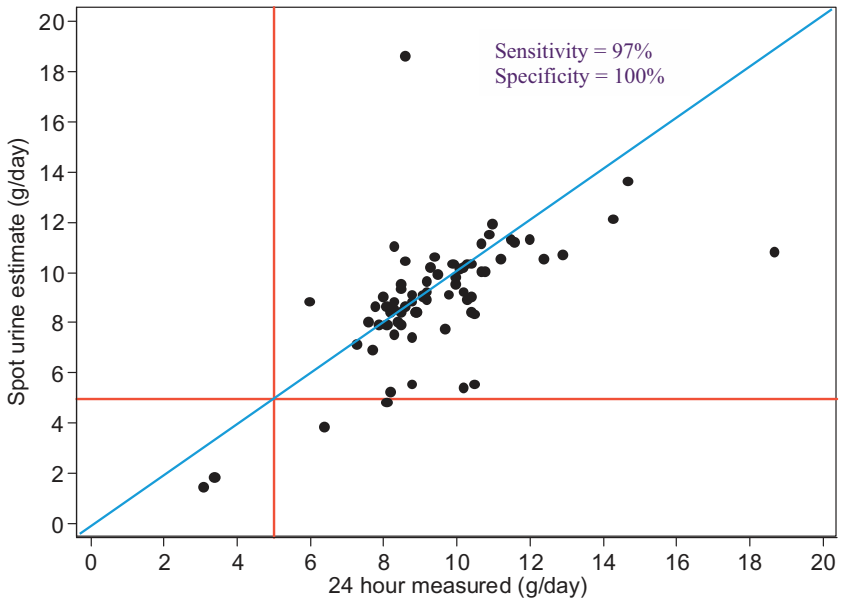

Figure 2. Comparison of mean population salt intake estimates based upon 24-h and spot urine samples and their capacity to classify salt intake above or below the WHO recommended maximum target (5 g/day) for 71 comparisons – vertical and horizontal lines are placed at 5 g/day intake level based upon measured daily salt intake using 24 hour collection and estimated daily salt intake using spot urine. The diagonal is the line of unity for measured and estimated daily salt intake.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

and 9.0 g/day (95% CI: 8.2, 9.7) based upon the spot urine samples.

Capacity for estimates based upon spot urine samples to classify mean population salt intake as above or below the 5 g/day WHO maximum recommended intake level

Estimates of mean population salt intake based upon spot urine samples were comparable to estimates based upon 24-h urine samples for the classification of mean population salt intake levels as above or below the WHO action point of 5 g/day. If the mean from 24-h urine samples is treated as an acceptable gold standard, then the estimates based upon the spot urine samples provided sensitivity of 97% and specificity of 100% for the 5 g/day threshold (Figure 2). This means that 97% of all populations with a true intake level above 5 g/day were identified by the methods based upon spot urine samples, and that all populations defined by spot urine samples as having an intake level above 5 g/day truly did. For just two of the 71 populations, the estimates based upon spot urine samples underestimated the true intake level such that the population was incorrectly classified as being below the 5 g/day cut point. Overall comparison of salt intake estimates was based on 24-h and spot urine samples.

The difference in estimated mean intake between spot and 24-h methods varied across intake levels defined by the 24-h sample with a non-zero slope ($\beta = -0.28$, 95% CI: -0.50, -0.06; $P = 0.013$) (Figure 3). In a sensitivity analysis, a single outlier[39] was excluded without making any material change to the results. Compared with estimates based upon the 24-h urine samples, estimates based upon the spot urine samples were higher at lower levels of salt intake and lower at higher levels of salt intake. For every gram per day increase of salt intake as determined from the 24-h urine samples, the estimates based upon the spot urine samples either over- or underestimated by approximately 0.3 g/day.

Comparison of salt intake estimates based on 24-h and spot urine samples in sub-group analyses

Mean population intake estimates based upon spot urine samples provided measures significantly different to those obtained from the 24-h urine samples for a number of subsets of the data (Table 2). For six subsets, the population mean estimated from spot urine samples differed by more than 1.0 g/day from that estimated using 24-h urine samples—Asian populations, use of the KAWASAKI formula, use of a simple formula with the spot urine samples, use of overnight urine samples, use of daytime urine samples and use of spot urine samples that were a part of the 24-h urine

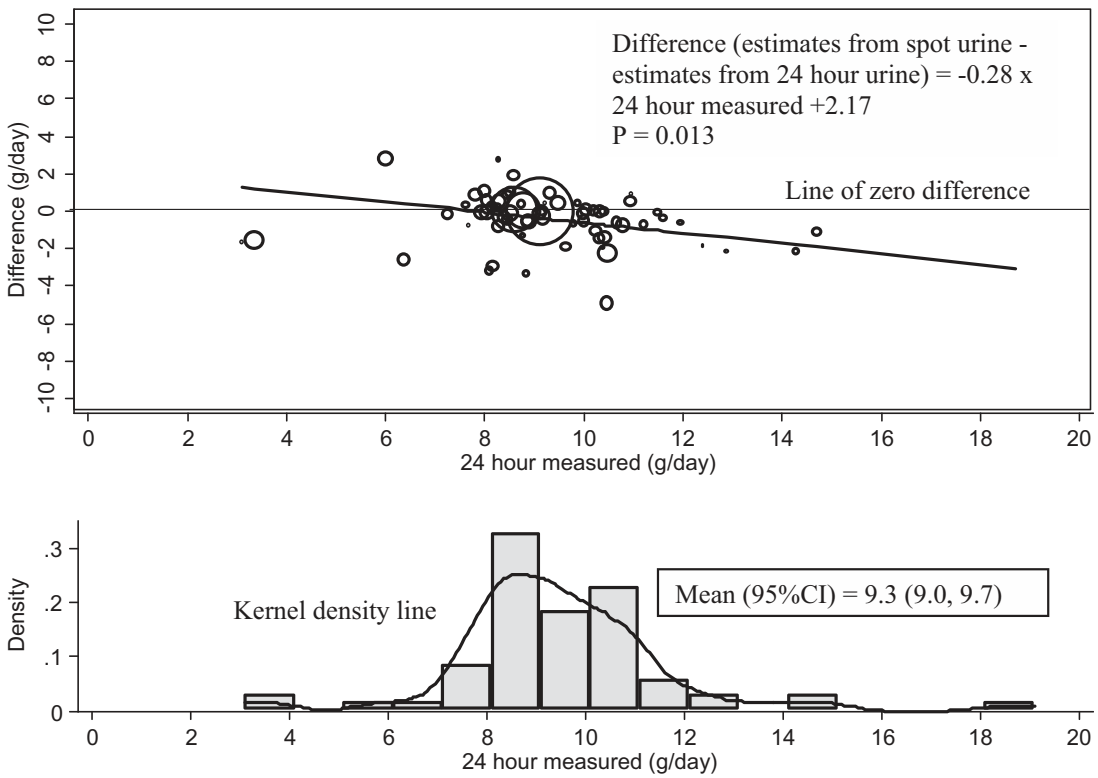

Figure 3. The difference between mean population salt intake estimates based upon 24-h and spot urine samples plotted against salt intake estimated from 24-h samples and distribution of population salt intake for 71 comparisons including 10 414 individuals.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

Table 2. Estimates of salt intake based on 24-h and spot urine samples and mean differences for subsets of the data

	No. of comparisons	Salt intake (g/day)		Difference (spot – 24-h), 95% CI	*P*-value for difference within subgroup	*P*-value for differences between subgroups
		Based upon 24-h urine samples	Based upon spot urine samples			
Overall	71	9.3	9.0	−0.4 (-0.7, -0.2)	<0.01	
Male population	53	10.4	10.0	−0.3 (-0.5, -0.1)	<0.01	0.84
Female population	44	8.2	7.9	−0.3 (-0.5, -0.2)	<0.001	
INTERSALT equation	38	9.4	9.2	−0.2 (-0.5, 0.0)	0.10	<0.001
TANAKA equation	14	8.9	9.1	0.2 (-0.2, 0.5)	0.30	
KAWASAKI equation	9	8.8	11.2	2.5 (1.5, 3.4)	<0.001	
By concentration	8	8.8	9.0	0.3 (-0.9, 1.6)	0.60	
By rate	22	9.5	8.1	−1.5 (-1.9, -1.1)	<0.001	
Morning urine	16	9.4	9.5	0.4 (-0.1,0.8)	0.09	<0.001
Evening urine	11	9.6	9.9	0.3 (-0.3, 0.9)	0.30	
Overnight urine	22	9.5	7.6	−1.9 (-2.8,-0.9)	<0.001	
Daytime urine	13	9.4	10.4	1.0 (0.6,1.4)	<0.001	
Casual urine	36	9.5	9.4	−0.1 (-0.3, 0.1)	0.49	
Developed countries	57	9.0	8.7	−0.4 (-0.6, -0.1)	0.01	0.59
Developing countries	13	10.6	9.9	−0.7 (-1.9, 0.5)	0.24	
Non-Asian countries	57	9.1	8.8	−0.3 (-0.5, 0.0)	0.07	0.16
Asian countries	13	10.4	9.0	−1.1 (-1.9, -0.2)	0.02	
Spot part of 24-h	313	9.4	8.1	−1.3 (-1.9, -0.8)	<0.001	<0.001
Spot separate from 24-h	38	9.4	9.5	0.2 (0.0, 0.3)	0.13	

collection (all $P < 0.05$). Lesser, but nonetheless statistically significant, differences were observed for several other subsets. For several characteristics there was evidence of heterogeneity in these findings across the data subsets including for estimating equation type, timing of spot urine collection and use of spot samples that were a part of the 24-h urine collection (all $P < 0.001$).

Discussion

These data provide strong support for the notion that estimates of mean population salt intake based upon spot urine samples can be used to make decisions about whether a country needs a programme to reduce average population salt consumption. This is an important observation because the WHO has recommended that all Member States with mean salt consumption above 5 g/day implement programmes to reduce salt intake by 30%. Many countries have no current direct estimate of salt intake from urine samples, and for many countries large-scale surveys based upon 24-h urine collections will be impractical.[10] Spot urine samples, which can be done much more easily as part of routine surveillance programmes, will offer a viable alternative for many countries. This will enable many countries around the world to make early and objective decisions about the priority that should be given to national efforts focused upon salt reduction.

The findings of our overview are consistent with a number of previous reports[11,43] but our systematic and quantitative summation of the data substantially extends knowledge about the strengths and weaknesses of estimation methods based upon spot urine samples. Key metrics for policy makers or governments wishing to understand the need for salt reduction in their country are the estimates of sensitivity and specificity, both of which are very high. The high values are driven by the substantial difference between mean intake levels of the populations included in the overview and the 5 g/day maximum target set by the World Health Organization. However, since most countries around the world are projected to have salt intake levels substantially more than 5 g/day,[52] estimates based upon spot urine samples are likely to discriminate well between countries that should and should not prioritize salt reduction efforts. It is of note that whereas 24-h urine is not in itself a true 'gold standard', it serves as a useful comparator for this evaluation since it is treated as such, and to all intents and purposes is the measure upon which decision making is based.

It is also clear from our analyses that mean population salt intake based upon spot urine samples is an imperfect estimator of intake based upon 24-h samples. In particular, the equations systematically over- and underestimate intake at different levels of consumption, and these effects could become large for populations distant from the centre of the distribution. The overestimation of intake by the equations at lower levels of intake determined from 24-h collections may be attributable to confounding caused by incomplete 24-h collections, but this would not explain the underestimation

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

observed at higher level of intake. The bias in estimation from using the equations will have implications for the use of serial spot urine samples as a method for detecting changes in average population salt consumption over time, with spot urine samples likely to underestimate the true magnitude of any reduction achieved unless an adjustment is made. Countries wishing to use spot urine to track changes in population salt intake will need to take into account the differential estimates of spot urine and 24-h urine. The collection of 24-h urine samples from a subset of those from which spot urine samples are obtained will enable a direct quantitative evaluation of the impact of the different estimating methods and is recommended, although mathematical adjustments are also possible.

In addition to varying across intake levels defined by 24-h urine samples, the magnitude of the difference between daily intake estimates based upon spot and 24-h urine samples was also observed to vary between subsets of the data defined by estimating equation choice, spot urine collection time, ethnicity of the study population and whether the spot urine was or was not a part of the 24-h specimen. The KAWASAKI equation stood out as a poor performer because it markedly overestimated mean population intake compared with 24-h samples. This may be attributable to the equation being used with spot urine samples other than the second morning urine samples. Earlier reports exploring the relative performance of different estimating equations have likewise identified differences in the performance of the equations.[18,43–45] The impact of timing of spot urine collection has also been the focus of earlier analyses[43,45] based upon physiological observations that sodium excretion exhibits a diurnal variation.[22,53] In our review, estimates based upon overnight urine collections were most discrepant, markedly underestimating daily intake compared with 24-h collections. For these and other differences observed, it was difficult to be sure that they were the primary causal factors for the observed differences because of the grouped nature of the data available for analysis. In particular, the collinearity of study characteristics across the various data subsets investigated made it difficult to disentangle which were the factors most important to good performance of estimating methods based upon spot urine samples.

A number of studies have reported upon the capacity of methods based upon spot urine samples to predict the salt consumption levels of individuals (rather than populations) and typically report a poor correlation between measures obtained from 24-h samples compared with spot urine samples.[14,29,33,54–58] It is important to be aware that this does not necessarily mean that the spot urine methods will also be a poor way of predicting average consumption levels for a population. Random errors that might be introduced by having worse estimates of consumption for each individual can potentially be controlled by the combination of data from multiple individuals, and likewise biases can be adjusted for by including covariates in the models, as has been done with the various estimating equations that have been developed to date.

This overview is strengthened by its systematic approach to the collation and analysis of data and the availability of estimates for a reasonably large number of populations. The key weakness is that the analysis is based upon study-level data and it has therefore not been possible to fully explore the factors that lead to better or worse prediction of salt excretion using methods based upon spot urine samples. A systematic review that brought together individual participant data from multiple studies upon which more sophisticated meta-analytic approaches could be performed would greatly enhance the conclusions that could be drawn.

In summary, whereas complete carefully collected 24-h urine samples will give a robust measure of mean population salt intake, they are hard to obtain on representative samples and are beyond the capacity of many countries to deliver. The data presented here suggest that estimates based upon spot urine samples offer a plausible alternative. The parallel collection of 24-h urine samples in a subset of those with spot urine samples will further the research agenda and will be particularly valuable when done serially as part of efforts to track changes over time. In the meantime, a research initiative able to compile and analyse individual participant datasets from studies that have already completed would likely provide valuable new insight.

Funding

This work was partially supported by funding from the National Health and Medical Research Council of Australia (Program Grant GNT1052555), The World Health Organization and the Victorian Health Promotion Foundation. BN is the recipient of a National Health and Medical Research Council of Australia Senior Research Fellowship (GNT1106947) and JW is supported by a joint National Health and Medical Research Council and Heart Foundation Career Development Fellowship (1082924).

Conflict of interest: J. W. is currently supported by a joint National Health and Medical Research Council and Heart Foundation Career Development Fellowship (1082924) and receives additional funding for work on salt reduction from Vichealth Promotion and the World Health Organization. This work was supported by funding from a National Health and Medical Research Council of Australia Program Grant. BN is the recipient of a National Health and Medical Research Council of Australia Principal Research Fellowship.

Supplementary data

Supplementary data are available at *IJE* online.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

References

1. O'Donnell M, Mente A, Rangarajan S *et al*. Urinary sodium and potassium excretion, mortality, and cardiovascular events. *N Eng J Med* 2014;**371:**612–23.
2. Mozaffarian D, Fahimi S, Singh GM *et al*. Global sodium consumption and death from cardiovascular causes. *N Eng J Med* 2014;**371:**624–34.
3. Shoaibi A, Ghandour R, Khatib R *et al*. Salt reduction as a population-based intervention for the prevention of coronary heart diseases: an economic assessment. *Lancet* 2013;**382:**S33.
4. WHO. *Guideline: Sodium Intake for Adults and Children*. Geneva: WHO, 2012.
5. WHO. *WHO Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020*. Geneva: World Health Organization, 2013.
6. Webster J. *Monitoring Population Salt Intake as Part of WHO STEPS*. Report of a meeting in Sydney, 2–4 December 2013. Sydney: George Institute for Global Health, 2013.
7. Pan American Health Organization–World Health Organization. *Strategies to Monitor and Evaluate Population Sodium Consumption and Sources of Sodium in the Diet*. Report of a joint technical meeting convened by WHO and the Government of Canada, 2010. Washington, DC: PAHO-WHO, 2010.
8. McGuire S; Institute of Medicine. *Strategies to Reduce Sodium Intake in the United States*. **Washington, DC**: National Academies Press, 2010.
9. Simpson FO. Sodium intake, body sodium, and sodium excretion. *Lancet* 1988;**2:**25–29.
10. WHO. *European Regional Technical Consultation on Noncommunicable Disease Surveillance, Monitoring and Evaluation*. Geneva: World Health Organization, 2012.
11. Brown IJ, Dyer AR, Chan Q *et al*. Estimating 24-h urinary sodium excretion from casual urinary sodium concentrations in Western populations: the INTERSALT study. *Am J Epidemiol* 2013;**177:**1180–92.
12. Chen WY, Hsieh BS, Cheng JT, Yen TS, Tseng WP, Chen CM. Plasma renin activity and sodium excretion in normal and hypertensive Chinese. *J Formos Med Assoc* 1975;**74:**525–33.
13. Kawasaki T, Itoh K, Uezono K, Sasaki H. A simple method for estimating 24 h urinary sodium and potassium excretion from second morning voiding urine specimen in adults. *Clin Exp Pharmacol Physiol* 1993;**20:**7–14.
14. Mann SJ, Gerber LM. Estimation of 24-h sodium excretion from spot urine samples. *J Clin Hypertens* 2010;**12:**174–80.
15. Tanaka T, Okamura T, Miura K *et al*. A simple method to estimate populational 24-h urinary sodium and potassium excretion using a casual urine specimen. *J Hum Hypertens* 2002;**16:**97–103.
16. Toft U, Cerqueira C, Andreasen AH *et al*. Estimating salt intake in a Caucasian population: can spot urine substitute 24-h urine samples? *Eur J Prev Cardiol*. 2014;**21:**1300–07.
17. Ji C, Miller MA, Venezia A, Strazzullo P, Cappuccio FP. Comparisons of spot vs 24-h urine samples for estimating population salt intake: Validation study in two independent samples of adults in Britain and Italy. *Nutr Metab Cardiovasc Dis* 2014;**24:**140–47.
18. Rhee MY, Kim JH, Shin SJ *et al*. Estimation of 24-h urinary sodium excretion using spot urine samples. *Nutrients* 2014; **6:**2360–75.
19. Huber DR, Blount BC, Mage DT, Letkiewicz FJ, Kumar A, Allen RH. Estimating perchlorate exposure from food and tap water based on US biomonitoring and occurrence data. *J Expo Sci Environ Epidemiol* 2011;**21:**395–407.
20. Mage DT, Allen RH, Kodali A. Creatinine corrections for estimating children's and adult's pesticide intake doses in equilibrium with urinary pesticide and creatinine concentrations. *J Expo Sci Environ Epidemiol* 2008;**18:**360–68.
21. Zimmermann MB, Andersson M. Assessment of iodine nutrition in populations: past, present, and future. *Nutr Rev* 2012;**70:**553–70.
22. Stanbury SW, Thomson AE. Diurnal variation in electrolyte excretion. Clin Sci 1951;**10:**267–93.
23. Scottish Centre for Social Research. *A Survey of 24 Hour Urinary Sodium Excretion in a Representative Sample of the Scottish Population as a Measure of Salt Intake*. 2011. http://www.natsal.ac.uk/media/752732/final%20report%20april l%202011%20all%20final%20%20report.pdf (23 February 2015, date last accessed).
24. Liu K, Cooper R, McKeever J *et al*. Assessment of the association between habitual salt intake and high blood pressure: methodological problems. *Am J Epidemiol* 1979;**110:**219–26.
25. Ding J, Liu L, Zheng D *et al*. Urinary Sodium and Aldosterone excretion of different time periods in normal subjects and their relatioship to 24 hr total excretion. *Acta Academiae Medicinae Sinicae* 1983;**3:**193–95.
26. Dyer AR, Stamler R, Grimm R *et al*. Do hypertensive patients have a different diurnal pattern of electrolyte excretion? *Hypertension* 1987;**10:**417–24.
27. Dyer AR, Martin GJ, Burton WN, Levin M, Stamler J. Blood pressure and diurnal variation in sodium, potassium, and water excretion. *J Hum Hypertens* 1998;**12:**363–71.
28. Kara PS, Erkoc R, Soyoral YU, Begenik H, Aldemir MN. Correlation of 24-h Urine Sodium, Potassium and Calcium Measurements with Spot Urine. *Eur J Gen Med* 2013;**10:**20–25.
29. Liu LS, Zheng DY, Lai SH, Wang GQ, Zhang YL. Variability in 24-h urine sodium excretion in Chinese adults. *Chin Med J (Engl)* 1986;**99:**424–26.
30. Liu LS, Zheng DY, Jin L, Liao YL, Liu K, Stamler J. Variability of urinary sodium and potassium excretion in north Chinese men. *J Hypertens* 1987;**5:**331–35.
31. Luft FC, Sloan RS, Fineberg NS, Free AH. The utility of overnight urine collections in assessing compliance with a low sodium intake diet. *JAMA* 1983;**249:**1764–68.
32. Luft FC, Fineberg NS, Sloan RS. Estimating dietary sodium intake in individuals receiving a randomly fluctuating intake. *Hypertension* 1982;**4:**805–08.
33. Luft FC, Fineberg NS, Sloan RS. Overnight urine collections to estimate sodium intake. *Hypertension* 1982;**4:**494–98.
34. Mill JG, Silva AB, Baldo MP, Molina MC, Rodrigues SL. Correlation between sodium and potassium excretion in 24- and 12-h urine samples. *Braz J Med Biol Res* 2012;**45:**799–805.
35. Pan WH, Chen JY, Chen YC, Tsai WY. Diurnal electrolyte excretion pattern affects estimates of electrolyte status based on 24-h, half-day, and overnight urine. *Chin J Physiol* 1994;**37:**49–53.
36. Bankir L, Bochud M, Maillard M, Bovet P, Gabriel A, Burnier M. Nighttime blood pressure and nocturnal dipping are associated with daytime urinary sodium excretion in African subjects. *Hypertension* 2008;**51:**891–98.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022

37. He J, Klag MJ, Whelton PK *et al*. Agreement between overnight and 24-h urinary cation excretions in southern Chinese men. *Am J Epidemiol* 1993;**137:**1212–20.
38. Kang SS, Kang EH, Kim SO, Lee MS, Hong CD, Kim SB. Use of mean spot urine sodium concentrations to estimate daily sodium intake in patients with chronic kidney disease. *Nutrition* 2012;**28:**256–61.
39. Wolf JP, Henriet MT, Nguyen NU, Dumoulin G, Laroze M, Berthelay S. Expression of plasma renin activity in terms of urinary sodium excretion and posture in normal subjects on free sodium intake. *Ren Physiol* 1984;**7:**237–42.
40. Subramanian S, Teo BW, Toh QC *et al*. Spot urine tests in predicting 24-h urine sodium excretion in Asian patients. *J Ren Nutr* 2013;**23:**450–55.
41. Iwahori T, Ueshima H, Miyagawa N *et al*. Six random specimens of daytime casual urine on different days are sufficient to estimate daily sodium/potassium ratio in comparison to 7-day 24-h urine collections. *Hypertens Res* 2014;**37):**765–71.
42. World Bank. *Data Countries and Economies*.2015. http://data.worldbank.org/country (15 August 2015, date last accessed).
43. Cogswell ME, Wang CY, Chen TC *et al*. Validity of predictive equations for 24-h urinary sodium excretion in adults aged 18-39 y. *Am J Clin Nutr* 2013;**98:**1502–13.
44. McLean R, Williams S, Mann J. Monitoring population sodium intake using spot urine samples: validation in a New Zealand population. *J Hum Hypertens* 2014;**28:**657–62.
45. Jeffery P, Land M, Riddle J *et al*. Correlation between 24-h and spot/void urine samples for the purpose of population salt intake assessment. *Ann Nutr Metab* 2013;**63**(Suppl 1) :1477. http://www.karger.com/Article/Pdf/354245.
46. Mente A, O'Donnell MJ, Dagenais G *et al*. Validation and comparison of three formulae to estimate sodium and potassium excretion from a single morning fasting urine compared to 24-h measures in 11 countries. *J Hypertens* 2014; **32:**1005–14.
47. Han W, Sun N, Chen Y, Wang H, Xi Y, Ma Z. Validation of the Spot Urine in Evaluating 24-h Sodium Excretion in Chinese Hypertension Patients. *Am J Hypertens* 2015;**28:**1368–75.
48. Follmann D, Elliott P, Suh I, Cutler J. Variance imputation for overviews of clinical trials with continuous response. *J Clin Epidemiol* 1992;**4:**769–73.
49. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials* 1986;**7:**177–88.
50. Higgins JP, Thompson SG. Controlling the risk of spurious findings from meta-regression. *Stat Med* 2004;**23:**1663–82.
51. Enkhtungalag B, Batjargal J, Chimedsuren O, Tsogzolmaa B, Anderson CS, Webster J. Developing a national salt reduction strategy for Mongolia. *Cardiovasc Diagn Ther* 2015;**5**:229–37.
52. Powles J, Fahimi S, Micha R *et al*. Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open* 2013;**3:**e003733.
53. Buchsbaum M, Harris EK. Diurnal variation in serum and urine electrolytes. *J Appl Physiol* 1971;**30:**27–35.
54. Ilich JZ, Blanusa M, Orlic ZC, Orct T, Kostial K. Comparison of calcium, magnesium, sodium, potassium, zinc, and creatinine concentration in 24-h and spot urine samples in women. *Clin Chem Lab Med* 2009;**47:**216–21.
55. Imai E, Yasuda Y, Horio M *et al*. Validation of the equations for estimating daily sodium excretion from spot urine in patients with chronic kidney disease. *Clin Exp Nephrol* 2011;**15:**861–67.
56. Kamata K, Tochikubo O. Estimation of 24-h urinary sodium excretion using lean body mass and overnight urine collected by a pipe-sampling method. *J Hypertens* 2002;**20:**2191–97.
57. Liu K, Stamler J. Assessment of sodium intake in epidemiological studies on blood pressure. *Ann Clin Res* 1984;**16**(Suppl 43):49–54.
58. Micheli ET, Rosa AA. Estimation of sodium intake by urinary excretion and dietary records in children and adolescents from Porto Alegre, Brazil: a comparison of two methods. *Nutr Res* 2003;**23:**1477–87.

Downloaded from https://academic.oup.com/ije/article/45/1/239/2363658 by guest on 20 August 2022