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Estimating population level 24-h sodium excretion using spot urine samples in older adults in rural South Africa

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Abstract

Background: South Africa has introduced regulations to reduce sodium in processed foods. Assessing salt consumption with 24-h urine collection is logistically challenging and expensive. We assess the accuracy of using spot urine samples to estimate 24-h urine sodium (24hrUNa) excretion at the population level in a cohort of older adults in rural South Africa.

Methods: 24hrUNa excretion was measured and compared to that estimated from matched spot urine samples in 399 individuals, aged 40–75 years, from rural Mpumalanga, South Africa.

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Conflicts of interest

None declared. In work unrelated to the subject matter of the paper, T.A.G. has received research funding from Novartis in the last year and is board member of the nonprofit organization, World Heart Federation.

Ethics approval

Ethics approval was obtained from the University of the Witwatersrand Human Research Ethics Committee, the Harvard T.H. Chan School of Public Health, Office of Human Research Administration, and the Mpumalanga Provincial Health Research Committee. All participants provided informed consent.

We used the Tanaka, Kawasaki, International Study of Sodium, Potassium, and Blood Pressure (INTERSALT), and Population Mean Volume (PMV) method to predict 24hrUNa at the individual and population level.

Results: The population median 24hrUNa excretion from our samples collected in 2017 was 2.6 g (interquartile range: 1.53–4.21) equal to an average daily salt intake of 6.6 g, whereas 65.4% of participants had a salt excretion above the WHO recommended 5 g/day. Estimated population median 24hrUNa derived from the INTERSALT, both with and without potassium, showed a nonsignificant difference of 0.25 g ($P = 0.59$) and 0.21 g ($P = 0.67$), respectively. In contrast, the Tanaka, Kawasaki, and PMV formulas were markedly higher than the measured 24hrUNa, with a median difference of 0.51 g ($P = 0.004$), 0.99 g ($P = 0.00$), and 1.05 g ($P = 0.00$) respectively. All formulas however performed poorly when predicting an individual's 24hrUNa,

Conclusion: In this population, the INTERSALT formulas are a well suited and cost-effective alternative to 24-h urine collection for the evaluation of population median 24hrUNa excretion. This could play an important role for governments and public health agencies in evaluating local salt regulations and identifying at-risk populations.

Keywords

salt; sodium; spot urine; 24-h; INTERSALT; South Africa; rural

INTRODUCTION

Worldwide, hypertension is currently the leading risk factor for adverse cardiometabolic disease (CMD) outcomes and mortality, with low- and middle-income countries (LMICs) experiencing the largest share of CMD-related premature deaths [1,2]. However, while CMD already contributes to significant morbidity and mortality it is poised to play an ever-increasing role in global disease burden given individuals over 65-years-old constitute the fastest growing age group globally [2–4]. Furthermore, the prevalence of hypertension is anticipated to rise sharply with aging populations and increased adoption of more westernized lifestyles and diets [5], a change already underway in urban and rural populations in South Africa with hypertension rates between 58% and 78% in older adults [6–8].

Dietary salt intake has been associated with raised blood pressure and increased mortality when consumption exceeds 5 g/day [9–11], with cardiovascular risk following a dose–response relationship with sodium intake [12]. To minimize the negative health implications of excess salt consumption the WHO has recommended restricting salt intake to <5 g/day (<2 g of sodium) [13]. In response, many countries have adopted regulations to curb salt intake. Globally, the primary focus has been on limiting sodium concentrations in bread [14]. Starting in 2016, South Africa has included 13 other categories of food in these regulations, ranging from savory snacks to stock powders and other processed foods and meats [15].

Since dietary recall is not a reliable measure of salt consumption the gold standard method is to assess 24-h urinary sodium (24hrUNa) excretion as a proxy [16]. This method is however

both cumbersome and logistically expensive making it difficult to scale up for population level monitoring. It may also be vulnerable to inherent selection bias due to the time demand required of participants, thus inadvertently selecting highly motivated persons who are most likely to have affected dietary changes.

Estimating 24hrUNa excretion using formulas applied to sodium levels derived from spot urine samples is a promising alternative that is cheaper and simpler to scale, enabling wider population sampling. The most used formulas include the Kawasaki [17], Tanaka [18], and INTERSALT [19]. These draw on parameters such as age, sex, BMI, and spot creatinine to account for unknown 24-h urine volumes and varying sodium excretion throughout the day. Other methods include using urine excretion rate to estimate 24-h volumes or utilizing the spot urine sodium and a mean 24-h population urine volume, collected either as part of a study or from estimates in similar populations [20,21]. Although many studies have shown these estimations to be inaccurate at the individual level, a meta-analysis of over 10 000 participants from 28 studies evaluating 71 formula comparisons demonstrated excellent sensitivity (97%) and specificity (100%) in determining whether mean population salt intake was below or above the WHO recommended 5 g/day using population mean estimates derived from spot urine samples [22]. Although at the individual level there appeared to be over- and underestimations at the lower and higher end of sodium excretion respectively, when looking at the overall trend of the equations the analysis concluded spot urine samples provided an effective indication of mean population salt excretion to inform local salt regulation policies.

Many studies have assessed the validity of using formulas to predict 24hrUNa excretion in populations other than those in which they were developed, suggesting age, ethnicity, and sex differences as possible modifying factors resulting in poor performance [23,24]. The few studies conducted within African populations have yielded mixed results, often pooling data from across diverse ethnic groups. A 2014 study of 1083 participants across 11 countries, of which South Africa was the sole African country, showed the Kawasaki formula best estimated population mean 24hrUNa excretion [25]. Two studies within South Africa both showed poor formula performance at the individual level with varying degrees of inaccuracy and proportional bias [26,27]. A study in Benin showed some utility for spot urine samples using an alternative arithmetic formula that required a 24-h urine creatinine [28]. These studies highlight both a paucity of evidence on the usefulness of these formulas for population level 24hrUNa excretion in African populations as well as a lack of validation in more homogenous populations. This considerable gap in the evidence underscores the need to understand the best methods to more easily and affordably survey population level salt consumption.

Aims/objectives

The primary objective of this study was to evaluate the accuracy of using spot urine sodium concentrations to estimate population median 24hrUNa excretion in a cohort of older adults in rural South Africa.

Secondary outcomes include determining measured 24hrUNa excretion, and therefore salt intake, in this locally representative cohort to assess alignment with WHO recommendations.

METHODS

Study setting and sampling

The participants for this study were part of the “Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community” (HAALSI) cohort in South Africa. HAALSI was established to describe biological, social, and economic determinants and consequences of health and ageing in rural South Africa. This cohort comprises 5059 people (46.4% men) aged 40years and over in the rural Agincourt region of the Bushbuckridge subdistrict, Mpumalanga Province, South Africa [7]. The study area from which the cohort was randomly selected consists of 31 villages with a total population of approximately 116 000 individuals [7]. From this original HAALSI cohort of 5059, a random sample of 3273 HAALSI participants, stratified by age, were invited to enroll in the HAALSI/AWI-Gen (Africa Wits-INDEPTH partnership for Genomics studies) sub-cohort. A total of 2486 individuals between 40–60yr old were enrolled in 2015 and of these participants, urine samples were successfully collected from 1947. From those that remained in the cohort in 2018, and from whom urine had been sampled in 2015, we randomly selected 400 and collected both 24-h and spot urine samples to assess the utility of using spot urine samples for making estimates about daily sodium intake.

Urine collection, processing, and analysis

For the spot urine samples, midstream urine samples were collected following procedures outlined by the WHO [29]. The first volume of urine was voided, after which 10–15 ml of midstream urine was collected into a container [30]. Samples were then transferred to the Agincourt laboratory where they were centrifuged at 1600g for 5 min to remove cellular debris and the resulting supernatant aliquoted into 2 ml cryovials. These cryovials were then stored at −80°C until being shipped to the assaying laboratory.

For 24-h urine samples, after a participant emptied their bladder during the spot urine collection, the time was noted, and the participant told to immediately commence 24-h urine collection [21]. The samples were then collected the next morning and taken to the Agincourt laboratory. Here, the total volume of urine collected was recorded, the samples thoroughly mixed, and a 15 ml sample extracted from the greater sample. As with the spot urines, the samples were centrifuged at 1600g for 5 min, the resulting supernatant aliquoted into 2 ml cryovials, and the cryovials stored at −80°C until assayed.

Urine creatinine was measured using a kinetic colorimetric assay, based on the Jaffé method, on the Roche/Hitache Cobas C501 System. The measuring range for the assay is 0.4–55 mmol/l (4.2–622 mg/dl). The laboratory coefficient of variation was <2.8%. Urine sodium and potassium were determined using the ion-selective electrode (ISE) module of the Roche/Hitache Cobas c system. The measuring range of the assay is 10–250 mmol/l for sodium, and 1–100 mmol/l for potassium. The laboratory coefficient of variation was <1.7%. Out-

of-range values at the upper limit of detection were assigned the maximal value (i.e. 250 mmol/l for sodium), while those at the lower limit of detection were assigned the minimal value (i.e. 10 mml/l for sodium). A sensitivity analysis, substituting half the minimum value for those at the lower limit of detection and a higher upper limit value based on a similar assay (i.e. 200 mmol/l for potassium and 400 mmol/l for sodium, using Beckman Coulter ISE modules upper limit values), was run to ensure this did not affect the primary outcome results.

Assessment of sodium excretion and salt intake

Measured 24hrUNa excretion was calculated as follows: 24hrUNa (mmol/ml) × total 24-h urine volume × molecular weight of sodium (22.99)/10 000 (converting units to grams). The formulas used for estimating 24hrUNa excretion were the Tanaka [18], Kawasaki [17], and INTERSALT [19], which utilizes a combination of spot urine sodium, creatinine, and potassium, along with sex, age, height, and weight (Table 1). An additional method, based on that conducted by Huang *et al.* [21], involved using spot urine in a similar manner to a 24-h urine sample (i.e. spot sodium concentration × mean 24-h urine volume of the study population, referred hereafter as the Population Mean Volume (PMV)). To calculate the 24-h salt (NaCl) intake, the 24hrUNa (g), either actual or estimated, was multiplied by 2.54 (according to the Na:Cl molecular mass ratio). The primary outcome was the difference between actual 24hrUNa excretion and that predicted using estimating formulas.

Statistical analysis

Data were assessed for normality using the Skewness-Kurtosis test, with continuous variables expressed as means and standard deviations (SD) and nonparametric data expressed as medians and interquartile ranges (IQR). Spearman's rho correlation and Wilcoxon signed rank test were used for nonnormal outcomes when assessing the associations and differences between actual and predicted 24hrUNa excretion. The Bland–Altman method was used to assess agreement between the formulas and regression coefficients calculated to evaluate degree of proportional bias [31]. Analyses were conducted using STATA V 17.0 software (StataCorp., College Station, Texas, USA), with $\alpha = 0.05$ to determine statistical significance. To address missing anthropometric measures in the dataset, height and weight values of the same participants collected during an earlier wave of data collection 3 years prior were used (Table S1, Supplemental Digital Content, http://links.lww.com/HJH/C104).

RESULTS

Of the 400 participants randomly selected from the HAALSI cohort to provide urine, one was excluded for only providing a spot urine sample. The remaining 399 provided both a spot urine and a 24-h urine sample and were therefore included in the analysis. Of the 399 participants, in comparison to the overall cohort, they were younger (57 vs. 65) and had higher median weight (72.9 kg vs. 70 kg) and BMI (26.1 vs. 28.0 kg/m^2) with similar heights (see Table S2, Supplemental Digital Content, http://links.lww.com/HJH/C104).

Participant characteristics are outlined in Table 2. 64.7% (n = 285) of participants were female, with a median age of 57 years (IQR: 50–64). The prevalence of hypertension was higher among women (61%) than men (50%). The mean urine volume provided was 1792 ml (SD: 882.4) and although 15/399 samples were below 500 ml, none were below 300 mL (an accepted cut off for exclusion), and 85% (n = 339) provided >1 l. The median 24hrUNa excretion was 2.6 g (IQR: 1.53–4.21), which equated to an average daily salt intake of 6.6 g. This was not meaningfully altered if all samples <500 ml were excluded (Table S3, Supplemental Digital Content, http://links.lww.com/HJH/C104) or if more conservative values were assigned to participants with values outside the assays range of detection (Table S4, Supplemental Digital Content, http://links.lww.com/HJH/C104 and Table S5, Supplemental Digital Content, http://links.lww.com/HJH/C104). There was considerable variation within the cohort, with daily sodium excretion ranging from 0.2 g (0.5 g of salt) to 14.7 g (37.3 g of salt), but most notable was that 65.4% of participants had sodium levels above that recommended by the WHO (i.e. 2 g/day) (Fig. 1 and Table 2). When stratified by sex, the median 24hrUNa for females and men were 2.6 g and 2.5 g, respectively (P = 0.58) (Fig. 2)

The median sodium excretions, as generated by each of the five equations, are outlined in Table 3. The estimated 24hrUNa median values were notably higher than the measured 24hrUNa median values with a median difference of 0.51 g (P = 0.004), 0.99 g (P = 0.00), and 1.05 g (P = 0.00) for the Tanaka, Kawasaki, and PMV, respectively. The INTERSALT value, with and without potassium, however showed an inconsequential difference compared to the measured 24hrUNa of 0.25 g (P = 0.59) and 0.21 g (P = 0.67), respectively.

No correlation between measured and estimated 24hrUNa was found except for the PMV formula (0.27, P = 0.00). Bland-Altman plots revealed the mean discrepancies between formulas were of a clinically negligible amount, with Tanaka overestimating by 0.07 g and the INTERSALTs, with and without potassium, underestimating by −0.27 g and −0.29 g respectively (Fig. 3). PMV and Kawasaki had more notable differences of −1.05 g and −0.77 g, respectively. There were however proportional biases with all equations, with regression coefficients of 1.12 (P = 0.00), 1.43 (P = 0.00), and 1.43 (P = 0.00) for Tanaka, and INTERSALTs with and without potassium respectively. PMV and Kawasaki had lower regression coefficients, 0.01 (P = 0.9) and 0.21 (P = 0.03), respectively, but in the case of the Kawasaki, was unreliable due to marked outliers. All formulas overestimated at the lower end of the spectrum and underestimated at the higher end. Although >94% of values fell within the limits of agreement (LOA) for all equations, the narrowest LOA, for the INTERSALTs, showed a range of 9.5 g of sodium, equating to 24.1 g of salt (range: −11.3 to 12.8 g) and the widest, for the Kawasaki, a range of 12 g of sodium (30.5 g of salt, range: −17.1 to 13.2 g) (Fig. 3).

DISCUSSION

In this rural South African population, we showed that overall median sodium consumption based on urine excretion was quite high (6.6 g salt/day) with over 60% of the population above the WHO recommended levels of 5 g/day. Further, we found that the INTERSALT equations both showed no notable difference in the median estimate of sodium excretion at

the population level when compared to the measured 24hrUNa. Thus, for this population they may have utility to assess sodium excretion at a population level over time. This is likely due to an averaging effect on key factors including variable daily sodium excretion, inconsistent creatinine excretion over the course of the day, and variable spot urine concentrations.

However, we also showed that all formulas performed poorly in their ability to estimate 24hrUNa at the individual level, as seen in the low level of correlations with Spearman's rho and the unacceptably wide Bland–Altman LOAs which would equate to clinically uninterpretable results. This suggests that change in spot urine is less likely to be helpful in evaluating a change in an individual's salt consumption, as opposed to the population level. The considerable proportional bias in all formulas also alludes to their lack of utility in determining an individual's 24hrUNa excretion. These findings have been replicated in several other studies within and outside of South Africa [22,26,27,32] and are likely due to inter- and intraday variability of sodium and creatinine excretion within an individual [16,25,33,34], compounded by the concentration of urine relative to fluctuating water consumption. The Tanaka and Kawasaki formulas are also sensitive to outlier results, either high spot urine sodium or low spot urine creatinine, as both divide spot sodium by spot creatinine in their equations. The INTERSALTs however appear to be slightly less vulnerable to over- or underestimations by avoiding both the above-mentioned concerns. The Tanaka formula, developed in Japanese individuals aged 20–59 years [18], and the Kawasaki formula, developed in Japanese individuals aged 20–79 years [17], may both overestimate creatinine and thus underestimate sodium, in an older and overweight cohort such as ours - considering that with increasing age creatinine will be expected to drop through diminishing muscle mass and, in more overweight populations, weight and BMI may be less reflective of underlying muscle mass [33].

The strengths of the INTERSALT formulas are the following: their widespread acceptability; their derivation using a larger more diverse population than both the Tanaka and Kawasaki; and their ability to adjust for potential confounders which may affect sodium excretion, such as creatinine (a marker of kidney function and urine concentration) and body habitus (height and weight), unlike the PMV Formula. The PMV formula, although far easier to implement by removing the need for creatinine, performed poorly overall despite using the mean urine volume from the exact same cohort, in contrast to the originating study by Huang *et al*. [22], which used a urine volume from a separate, ethnically similar population. Having an ability to estimate salt consumption in a population using the INTERSALT equation in South Africa may be helpful to both monitor the impact of the sodium legislation and the impacts reductions in consumption could have on population health. Most recently, the China Salt Substitute and Stroke study showed improvements across all CMD outcomes as well as mortality with moderate substitution of dietary salt in hypertensive subjects over the age of 60 years [35]. Models in rural South Africa suggest a modest reduction in salt intake of 0.85 g/person/day could likewise prevent 8% of strokes, 6.5% of ischemic heart disease, and 11% of hypertensive heart disease cases [36].

The INTERSALTs also showed a less prominent proportional bias than the other formulas. Its tendency to underestimate 24hrNa at the high end of the spectrum means those found to

have high sodium can be viewed with more certainty. These findings were replicated and expanded on by the SAGE group showing a specificity of 100% for the INTERSALTs in detecting mean salt excretion >5 g [26]. Such findings add more confidence to its use at the population level in correctly classifying populations with markedly raised sodium intake.

We found in this study that the levels of sodium excretion between men and women were similar. This was also seen in another South African population study of older adults [26]. However, in other studies in other countries, sodium excretion tends to be higher in males than females. This difference may be due to an association between BMI and sodium consumption since sodium consumption appears to be positively associated with BMI [37–39], particularly among women [40]. It may therefore be that the difference in BMI (higher in females than in males) in our cohort mitigates somewhat the expected difference. Further studies to understand this relationship would add to the recommendations of both weight and salt reduction for improvements in blood pressure control.

Key strengths of this study are the evaluation of an under-represented rural population with a high prevalence of hypertension, the large sample size, the evaluation of widely utilized equations, as well as the testing of the more affordable and simpler PMV method. Considering the equality of the INTERSALT with and without potassium in accurately determining population median sodium, we believe the INTERSALT without potassium specifically is preferable due to its lower associated laboratory costs. At 2.89 g/day and 2.85 g/day, respectively, they were also able to accurately show this population's median sodium consumption was well above the WHO recommended 2 g/day. Recommendations for future work would be to determine the INTERSALT's effectiveness in assessing change in sodium excretion over time using serial evaluations within the same population.

Based on our findings, we believe key prerequisites for using a formula for predicting 24hrNa are to: ensure results are not used for individuals but instead at the population level; validate the formula to be used in the population, and age group, of interest to ensure variations in creatinine and body composition are accounted for; consider the value of assessing 24-h creatinine within the population of interest to minimize systematic bias based on incorrect assumptions built into the formulas.

Limitations

Spot urine samples were collected immediately prior to commencing 24-h urine collection, and thus differences between the two samples may be attributable to lifestyle differences between the two consecutive days. This may have contributed further to the poor performance of these equations at the level of the individual. Spot samples were also collected throughout the course of the day and therefore did not meet expected collection requirements for the Kawasaki equation (second urine sample on waking). This may have therefore affected the results associated with the Kawasaki equation.

In conclusion, although the Tanaka, Kawasaki, and INTERSALT equations perform poorly at the individual level, our findings suggest both INTERSALT equations are well suited and cost-effective alternatives to 24-h urine collection to accurately evaluate population median 24hrUNa excretion in this rural South African setting. These formulas could play a valuable

role in the growing toolkit available to governments and public health agencies in LMICs in assessing key at-risk populations to inform local salt regulations, health advertisement campaigns, and targeted intervention strategies. However, more work is needed to develop tailored prediction equations to better represent populations within LMICs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Author contributions: J.D.T. and T.A.G. designed the analysis and wrote the manuscript. J.D.T. and N.J.C. performed the statistical analysis.

All authors interpreted the data, revised, and approved the manuscript.

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Data availability statement

The data supporting the findings of this study are available from the corresponding author on reasonable request. The datasets generated for the HAALSI cohort are available at the Harvard Centre for Population and Development Studies (HCPDS) program website: www.haalsi.org.

Abbreviations:

24hrUNa	24-h urine sodium
BMI	body mass index
CMD	cardiometabolic disease
IQR	interquartile range
LMIC	low- and middle-income countries
LOA	limits of agreement
NaCl	sodium chloride (salt)
PMV	Population Mean Volume
SD	standard deviation

REFERENCES

1. WHO. Global status report on noncommunicable diseases, 2014. Geneva: World Health Organisation (WHO); 2014.
2. Forouzanfar MH, Afshin A, Alexander LT, Biryukov S, Brauer M, Cercy K, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet 2016; 388:1659–1724. [PubMed: 27733284]
3. United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights.
4. Wang H, Naghavi M, Allen C, Barber RM, Carter A, Casey DC, et al. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet 2016; 388:1459–1544. [PubMed: 27733281]
5. WHO. Global action plan for the prevention and control of non-communicable diseases 2013–2020. Geneva: World Health Organisation (WHO); 2013.
6. Gaziano TA, Abrahams-Gessel S, Gomez-Olive FX, Wade A, Crowther NJ, Alam S, et al. Cardiometabolic risk in a population of older adults with multiple co-morbidities in rural South Africa: the HAALSI (Health and Aging in Africa: longitudinal studies of INDEPTH communities) study. BMC Public Health 2017; 17:1–10. [PubMed: 28049454]
7. Gómez-Olivé FX, Montana L, Wagner RG, Kabudula CW, Rohr JK, Kahn K, et al. Cohort profile: health and ageing in Africa: a longitudinal study of an INDEPTH Community in South Africa (HAALSI). Int J Epidemiol 2018; 47:689–690. [PubMed: 29325152]
8. Lloyd-Sherlock P, Beard J, Minicuci N, Ebrahim S, Chatterji S. Hypertension among older adults in low- and middle-income countries: prevalence, awareness and control. Int J Epidemiol 2014; 43:116–128. [PubMed: 24505082]
9. Mozaffarian D, Fahimi S, Singh GM, Micha R, Khatibzadeh S, Engell RE, et al. Global sodium consumption and death from cardiovascular causes. N Engl J Med 2014; 371:624–634. [PubMed: 25119608]
10. Cook NR, Appel LJ, Whelton PK. Lower levels of sodium intake and reduced cardiovascular risk. Circulation 2014; 129:981–989. [PubMed: 24415713]
11. Mente A, O'Donnell M, Rangarajan S, McQueen M, Dagenais G,Wielgosz A, et al. Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. Lancet 2018; 392:496–506. [PubMed: 30129465]
12. Ma Y, He FJ, Sun Q, Yuan C, Kieneker LM, Curhan GC, et al. 24-Hour urinary sodium and potassium excretion and cardiovascular risk. N Engl J Med 2022; 386:252–263. [PubMed: 34767706]
13. WHO. Guideline: sodium intake for adults and children. Geneva: World Health Organisation (WHO); 2012.
14. Trieu K, Neal B, Hawkes C, Dunford E, Campbell N, Rodriguez-Fernandez R, et al. Salt reduction initiatives around the world – a systematic review of progress towards the global target. DeAngelis MM, editor. PLoS One. 2015;10:e0130247. [PubMed: 26201031]
15. National Department of Health South Africa. Regulations relating to the reduction of sodium in certain foodstuffs and related matters. Government notice R214 in Government Gazette 36274, dated 20 March 2013. 2019.
16. Freedman LS, Commins JM, Moler JE, Willett W, Tinker LF, Subar AF, et al. Pooled results from 5 validation studies of dietary self-report instruments using recovery biomarkers for potassium and sodium intake. Am J Epidemiol 2015; 181:473–487. [PubMed: 25787264]
17. 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. [PubMed: 8432042]
18. Tanaka T, Okamura T, Miura K, Kadowaki T, Ueshima H, Nakagawa H.A simple method to estimate populational 24-h urinary sodium and potassium. J Hum Hypertens (16):2002;97–103. [PubMed: 11850766]

19. Brown IJ, Dyer AR, Chan Q, et al. Estimating 24-hour urinary sodium excretion from casual urinary sodium concentrations in Western populations. The INTERSALT Study. Am J Epidemiol 2013; 177:1180–1192. [PubMed: 23673246]
20. Mohammadifard N, Marateb H, Mansourian M, Khosravi A, Abdollahi Z, Campbell NRC, et al. Can methods based on spot urine samples be used to estimate average population 24h sodium excretion? Results from the Isfahan Salt Study. Public Health Nutr 2020; 23:202–213. [PubMed: 31547894]
21. Huang L, Woodward M, Stepien S, Tian M, Yin X, Hao Z, et al. Spot urine samples compared with 24-h urine samples for estimating changes in urinary sodium and potassium excretion in the China Salt Substitute and Stroke Study. Int J Epidemiol 2018; 47:1811–1820. [PubMed: 30307504]
22. Huang L, Crino M, Wu JHY, Woodward M, Barzi F, Land MA, et al. Mean population salt intake estimated from 24-h urine samples and spot urine samples: a systematic review and meta-analysis. Int J Epidemiol 2016; 45:239–250. [PubMed: 26796216]
23. 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; 24:140–147. [PubMed: 24119990]
24. Peng Y, Li W, Wang Y, Chen H, Bo J, Wang X, et al. Validation and assessment of three methods to estimate 24-h urinary sodium excretion from spot urine samples in Chinese adults. PLoS One 2016; 11:e0149655. [PubMed: 26895296]
25. Mente A, O'Donnell MJ, Dagenais G, Wielgosz A, Lear SA, McQueen MJ, 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. Hypertension 2014; 32:1005–1015.
26. Charlton K, Ware LJ, Chidumwa G, Cockeran M, Schutte AE, Naidoo N, et al. Prediction of 24-h sodium excretion from spot urine samples in South African adults: a comparison of four equations. J Hum Hypertens 2020; 34:24–33. [PubMed: 31076654]
27. Swanepoel B, Schutte AE, Cockeran M, Steyn K, Wentzel-Viljoen E.Monitoring the South African population's salt intake: spot urine v. 24 h urine. Public Health Nutr 2018; 21:480–488. [PubMed: 29125092]
28. Mizéhoun-Adissoda C, Houehanou C, Chianéa T, Dalmay F, Bigot A, Preux PM, et al. Estimation of daily sodium and potassium excretion using spot urine and 24-hour urine samples in a black population (Benin). J Clin Hypertens 2016; 18:634–640.
29. WHO. Guidelines for the collection of clinical specimens during field investigation of outbreaks, 2000. Geneva: World Health Organisation (WHO); 2000.
30. Ali SA, Soo C, Agongo G, Alberts M, Amenga-Etego L, Boua RP, et al. Genomic and environmental risk factors for cardiometabolic diseases in Africa: methods used for Phase 1 of the AWI-Gen population cross-sectional study. Glob Health Action 2018; 11 (Suppl 2).
31. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res (8):1999;135–160. [PubMed: 10501650]
32. Cogswell ME, Maalouf J, Elliott P, Loria CM, Patel S, Bowman BA. Use of urine biomarkers to assess sodium intake: challenges and opportunities. Annu Rev Nutr 2015; 35:349–387. [PubMed: 25974702]
33. Kampmann J, Siersbaek-Nielsen K, Kristensen M, Hansen JM. Rapid evaluation of creatinine clearance. Acta Med Scand 1974; 196:517–520. [PubMed: 4456984]
34. Ducharme MP, Smythe M, Strohs G. Drug-induced alterations in serum creatinine concentrations. Ann Pharmacother 1993; 27:622–633. [PubMed: 8347916]
35. Neal B, Wu Y, Feng X, Zhang R, Zhang Y, Shi J, et al. Effect of salt substitution on cardiovascular events and death. N Engl J Med 2021; 385:1067–1077. [PubMed: 34459569]
36. Bertram MY, Steyn K, Wentzel-Viljoen E, Tollman S, Hofman KJ.Reducing the sodium content of high-salt foods: Effect on cardiovascular disease in South Africa. S Afr Med J 2012; 102:743–745. [PubMed: 22958695]
37. Feng Q, Yuan S, Yang Q, Lu Y, Loos RJF, Li GHY, et al. Causal associations between urinary sodium with body mass, shape and composition: a Mendelian randomization study. Sci Rep 2020;10:17475. [PubMed: 33060734]

38. Stern N, Buch A, Goldsmith R, Nitsan L, Margaliot M, Endevelt R, et al. The role of caloric intake in the association of high salt intake with high blood pressure. Sci Rep 2021; 11:15803. [PubMed: 34349181]

39. Oh SW, Koo HS, Han KH, Han SY, Chin HJ. Associations of sodium intake with obesity, metabolic disorder, and albuminuria according to age. PLoS One 2017; 12:e0188770. [PubMed: 29244825]

40. Yi SS, Firestone MJ, Beasley JM. Independent associations of sodium intake with measures of body size and predictive body fatness. Obesity 2015; 23:20–23. [PubMed: 25294369]

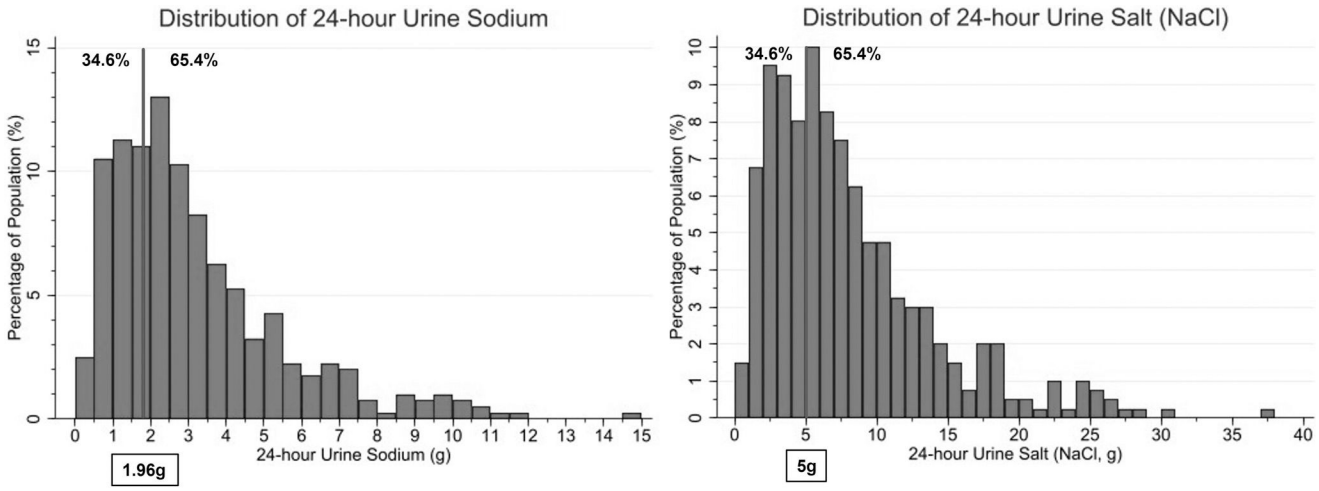

FIGURE 1.

Distribution of 24-h sodium and salt among participants (measured). Red line indicates WHO recommended sodium/salt intake in g/24-h. Percentages in chart area indicates percentage of participants above or below the WHO recommended level. NaCl, sodium chloride.

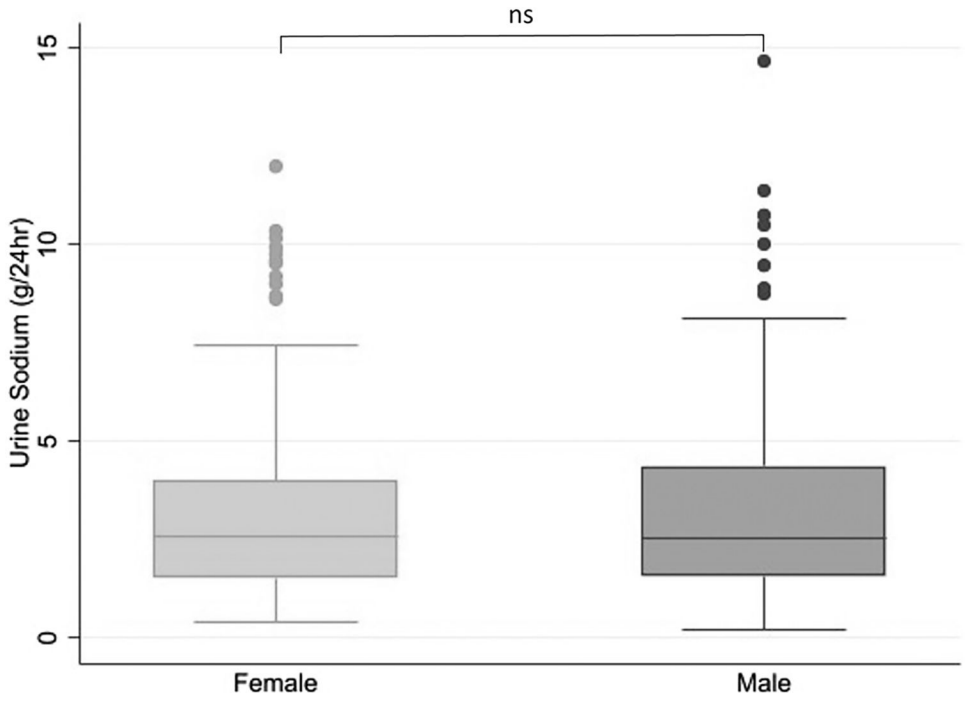

FIGURE 2.

Box plot of 24-h urine sodium by sex. Box denotes interquartile range (IQR) with median represented as the middle line. Potential outliers are identified as dots (1.5 times the IQR above the upper quartile). Nonsignificant (ns) difference noted between females and males ($P = 0.58$). Na, sodium.

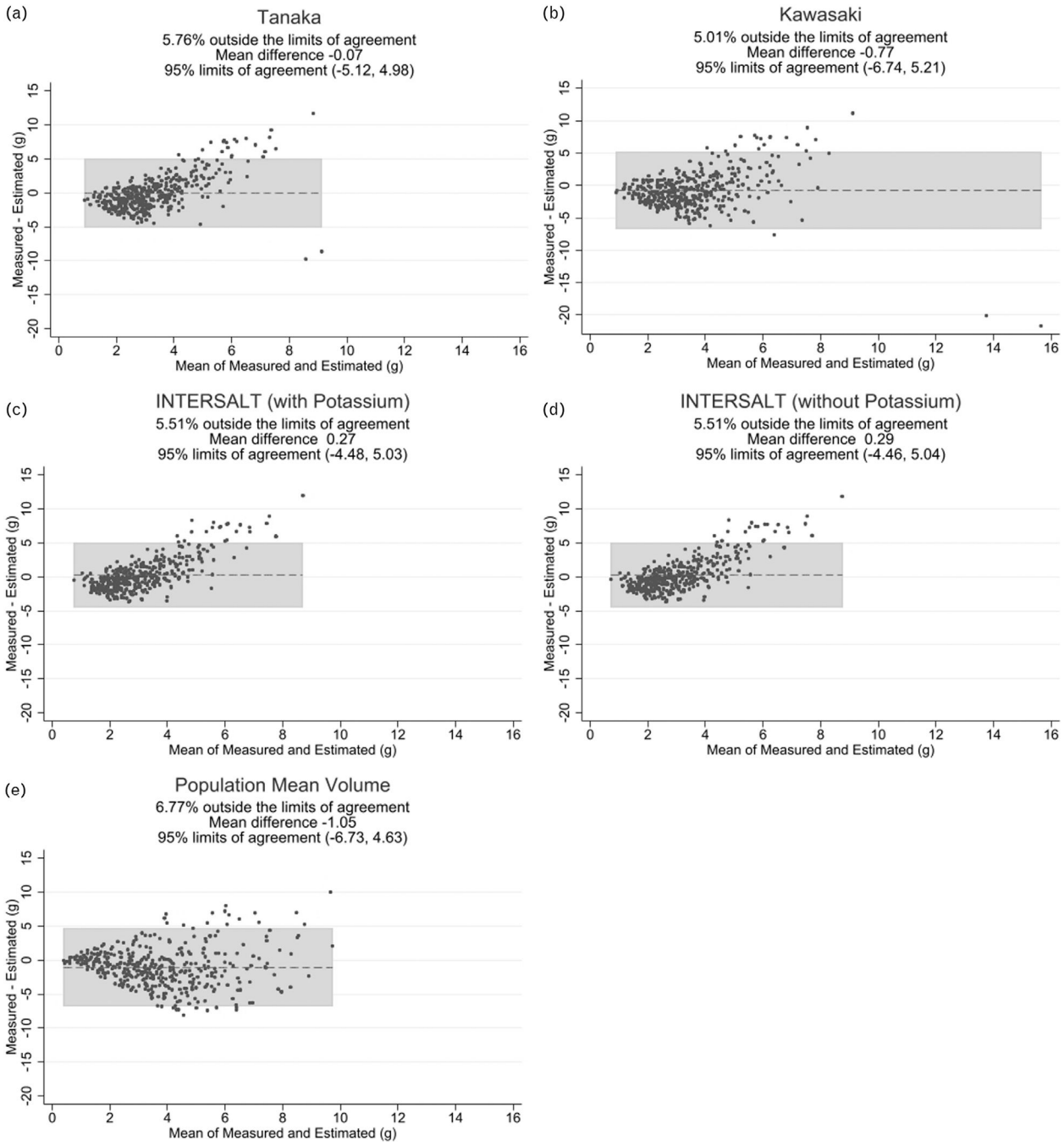

FIGURE 3.

Bland-Altman Plot assessing agreement between measured and estimated 24-hour urine sodium derived by formula.

TABLE 1.

Formulas used to calculate 24-h urine sodium using spot urine samples

Estimating method	Formula to estimate 24-h sodium excretion (g)
Tanaka	$23/1000 \times 21.98 \times (\text{spot Na [mmol/l]}/\{\text{spot creatinine [mg/dl]} \times 10\} \times \{-2.04 \times \text{age [years]} + 14.89 \times \text{weight [kg]} + 16.14 \times \text{height [cm]} - 2244.45\})^{0.392}$
Kawasaki	
Male	$23/1000 \times 16.3 \times (\text{spot Na [mmol/l]}/\{\text{spot creatinine [mg/dl]} \times 10\} \times \{-12.63 \times \text{age [years]} + 15.12 \times \text{weight[kg]} + 7.39 \times \text{height [cm]} - 79.9\})^{0.5}$
Female	$23/1000 \times 16.3 \times (\text{spot Na [mmol/l]}/\{\text{spot creatinine [mg/dl]} \times 10\}) \times (-4.72 \times \text{age [years]} + 8.58 \times \text{weight [kg]} + 5.09 \times \text{height [cm]} - 74.5\})^{0.5}$
INTERSALT with potassium	
Male	$23/1000 \times (25.46 + 0.46 \times \text{spot Na [mmol/l]} - 2.75 \times \text{spot creatinine [mmol/l]} - 0.13 \times \text{spot K [mmol/l]} + 4.1 \times \text{BMI [kg/m}^2\text{]} + 0.26 \times \text{age [years]})$
Female	$23/1000 \times (5.07 + 0.35 \times \text{spot Na [mmol/l]} - 2.16 \times \text{spot creatinine [mmol/l]} - 0.09 \times \text{spot K [mmol/l]} + 2.39 \times \text{BMI [kg/m}^2\text{]} + 2.35 \times \text{age [years]} - 0.03 \times \text{age}^2 \text{ [years]})$
INTERSALT without potassium	
Male	$23/1000 \times (23.51 + 0.45 \times \text{spot Na [mmol/l]} - 3.09 \times \text{spot creatinine [mmol/l]} + 4.16 \times \text{BMI [kg/m}^2\text{]} + 0.22 \times \text{age [years]})$
Female	$23/1000 \times (3.74 + 0.33 \times \text{spot Na [mmol/l]} - 2.44 \times \text{spot creatinine [mmol/l]} + 2.42 \times \text{BMI [kg/m}^2\text{]} + 2.34 \times \text{age [years]} - 0.03 \text{ age}^2 \text{ [years]})$
Population mean volume	(spot Na [mmol/l] × population mean 24 h urine volume [ml]/1000)/1000 × 22.989769)

BMI, body mass index; K, potassium; Na, sodium.

TABLE 2.

Participant characteristics

Characteristic	All (*n* = 399)	Female (*n* = 258)	Male (*n* = 141)
Age (years)	57 (50–64)	57 (51–64)	58 (50–64)
Height (cm)[a]	162 (158–168)	160 (156–163)	170 (165.3–175)
Weight (kg)[a]	72.9 (63–85)	74 (64–86)	71.2 (60.4–83)
BMI (kg/m^2)[a]	28 (23–32)	29 (25–34)	25 (21–29)
24-h urine volume, ml (mean, SD)	1791.8 (882.4)	1781.2 (861.1)	1811.1 (922.8)
24-h sodium (g)	2.6 (1.5–4.2)	2.6 (1.5–4)	2.5 (1.6–4.4)
24-h salt (NaCl) (g)	6.6 (3.9–10.7)	6.5 (3.9–10.2)	6.5 (4–11.1)

All results are displayed as median and interquartile range unless otherwise stated.

BMI, body mass index; NaCl, sodium chloride (salt); SD, standard deviation.

[a]Includes imputed values. No significant difference if excluded (Table S1, Supplemental Digital Content, http://links.lww.com/HJH/C104).

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TABLE 3.

Comparison of measured and estimated median 24-h sodium using five different formulas

	Median (IQR)	Median difference (IQR) between measured and estimated sodium	*P*-value of median difference[a]	Spearman's rho correlation coefficient (*P*-value)
Measured 24-h sodium	2.57 (1.53–4.21)	–	–	–
Tanaka	3.12 (2.54–3.88)	−0.51 (−1.78–0.95)	0.004	0.07 (0.15)
Kawasaki	3.78 (2.81–4.71)	−0.99 (−2.48–0.63)	0.000	0.09 (0.08)
INTERSALT (with K)	2.89 (2.29–3.5)	−0.25 (−1.31–1.23)	0.587	0.13 (0.01)
INTERSALT (without K)	2.85 (2.28–3.45)	−0.21 (−1.34–1.24)	0.667	0.14 (0.01)
Population mean volume (PMV)	4.08 (2.39–5.93)	−1.05 (−2.77–0.47)	0.000	0.27 (0.00)

IQR, interquartile range; K, potassium.

[a]Wilcoxon signed rank test.