

Intra-individual and inter-individual variations in iodine intake and excretion in adult women: implications for sampling

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Abstract

Iodine intake and excretion vary widely; however, these variations remain a large source of geometric uncertainty. The present study aims to analyse variations in iodine intake and excretion and provide implications for sampling in studies of individuals or populations. Twenty-four healthy women volunteers were recruited for a 12-d sampling period during the 4-week experiment. The duplicate-portion technique was used to measure iodine intake, while 24-h urine was collected to estimate iodine excretion. The mean intra-individual variations in iodine intake, 24-h UIE (24-h urinary iodine excretion) and 24-h UIC (24-h urinary iodine concentration) were 63, 48 and 55 %, respectively, while the inter-individual variations for these parameters were 14, 24 and 32 %, respectively. For 95 % confidence, approximately 500 diet samples or 24-h urine samples should be taken from an individual to estimate their iodine intake or iodine status at a precision range of ± 5 %. Obtaining a precision range of ± 5 % in a population would require twenty-five diet samples or 150 24-h urine samples. The intra-individual variations in iodine intake and excretion were higher than the inter-individual variations, which indicates the need for more samples in a study on individual participants.

Key words: Variation: Iodine intake: Iodine excretion: Adult women

Iodine, as an essential trace element, is critical for the synthesis of thyroid hormones. The main sources of iodine are diet and iodised salt, and dietary iodine intake is the most direct and reliable indicator of individual iodine intake. However, most studies have demonstrated that it is difficult to accurately assess iodine intake from diet, since no valid and feasible dietary method is available⁽¹⁾. FFQ tend to overestimate dietary iodine intake in individuals, while dietary records only represent dietary intake over the most recent few days⁽¹⁾. Iodine is primarily excreted in urine. Therefore, UIE (urinary iodine excretion; $\mu\text{g}/\text{d}$) is an indicator of recent iodine intake. UIC (urinary iodine concentration) is recommended by the WHO to be the indicator for evaluating iodine status in populations⁽²⁾.

It is well known that variations in iodine intake and excretion could be significant at any study scale. At the individual scale, iodine intake fluctuates greatly through daily intake, while iodine excretion in urine could be affected by factors such as hydration

status^(3,4). At the population level, economic status, iodine supplementation, dietary habits, etc. would result in considerable variation in iodine intake and excretion among different populations.

Substantial intra-individual and inter-individual variations affect the reliability of estimates of iodine intake and iodine excretion⁽⁴⁾. It is difficult to accurately measure daily iodine intake and excretion, so spot urine is usually used to assess iodine status. Some studies have examined variations in the urine iodine concentration of spot urine^(5,6). However, we analysed the variation in iodine intake and excretion at the intra- and inter-individual levels by collecting duplicate portion food and 24-h urine samples to accurately assess daily iodine intake and excretion. Finally, we estimated the sample size needed for individual- and population-level studies aiming to characterise iodine intake from diet by the duplicate-portion technique and iodine excretion from 24-h urine samples.

Abbreviations: UIC, urinary iodine concentration; UIE, urinary iodine excretion.

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Materials and methods

Study design

This iodine balance study was conducted in November 2014 over 4 weeks to obtain the appropriate recommended nutrient intake of iodine for Chinese women. Twenty-four healthy volunteer women were recruited from Tianjin Medical University. Women with abnormal thyroid function or a high level of urinary iodine concentration (exceeded 300 µg/l) were excluded. The volunteers were assigned to receive prescribed diets prepared by the university kitchen with duplicate portions retained for 12 d in 4 weeks (Fig. 1). The duplicate-portion technique with subsequent chemical analysis was used to obtain valid estimates of iodine intake from the diets of the adult women, and 24-h urine samples were collected to measure their daily iodine excretion. A detailed description of the study population and design was previously reported in Tan *et al.*⁽⁷⁾.

All procedures were approved by the Ethics Committee of Tianjin Medical University according to the Code of Ethics of the World Medical Association (Declaration of Helsinki). Written informed consent was obtained from each participant. Information on the present study has been registered on [ClinicalTrials.gov](https://www.clinicaltrials.gov) (ID: NCT03279315).

Dietary iodine intake

Nutritionally and energetically adequate diets with measured iodine content were devised. Participants were required to eat the prescribed diet for 4 weeks, and every woman received the same food on the same day. During the experiment, on 3 d in each week (including working and weekend days), the amount of food before and after the meal was carefully weighed and the intake amount of each meal for each participant was calculated. The subjects were asked to return the duplicated portions of the meal that they actually ate. All food samples were weighed, homogenised, lyophilised and preserved in a freezer at -20 °C until further analyses. The daily iodine intake of the diet of each participant was measured and calculated.

Urinary iodine excretion

Twelve 24-h urine samples were also collected from each participant on the same day as the diet sample. Participants were asked to void their bladder before 08.00 hours and then collect all urine over the following 24 h, including the first morning void at 08.00 hours the next morning. Urine volume and urinary iodine concentration were measured. The total 24 h iodine excretion was calculated for each subject by multiplying the UIC (µg/l) by the total urine volume (litres).

Iodine content measurement

Laboratory analysis of food and urine was completed by the Central Laboratory of Preventive Medicine at Tianjin Medical University using nationally standardised and validated methods. The national standard method (As-Ce catalytic spectrophotometry) was used for measurements of iodine content in diet and urine with quality control.

Statistical analysis and calculations

All data were analysed in SAS version 9.4 (SAS Institute). The statistical description and variability of iodine intake, 24-h UIE, excretion rate and 24-h UIC were described as the mean, median, variance and CV%. The CV% was the square root of the variance divided by the mean as a percentage. The estimated sample size with specified precisions was calculated by the equation $N = (Z \times CV\% / D)^2$ ⁽⁴⁾. The precision range (*D*) is used to estimate the precision of a set point in biochemical variables and was recommended for estimating the number of samples required for biochemical measurements. In our study, the precision range (*D*) used in the calculations varied from ±1 to ±50% and the CI used (*Z*) was 1.96 for 95%. Using Z statistics may underestimate the sample size for a small *n* by up to 30% compared with that estimated by t-statistics but was chosen in order to comply with the recommendations described by Fraser & Harris⁽⁸⁾. The mean intra- and inter-individual variances were similar whether they were assessed as the mean variance among individuals or using ANOVA techniques. The CV% was used to calculate the sample size for iodine intake and excretion with a specified precision range for intra-individual and inter-individual variations.

Results

Twenty-four healthy women participated in the present study, with a mean age of 22 (SD 1.39) years and a median BMI of 20 (18, 21) kg/m². Dietary iodine intake, 24-h UIE and 24-h UIC were reported, and the excretion rate (24-h UIE/dietary intake) was calculated.

Table 1 presents the descriptions of and variations in iodine intake and excretion in individual participants. Each participant provided twelve diet and urine samples during the experiment. Individuals (*n* 12) had a mean dietary iodine intake of 269 µg/d, and the mean 24-h UIE from the 24-h urine samples was 133 µg/d (113 µg/l for 24-h-UIC). The mean excretion rate of iodine at the individual level was 0.55, which means that approximately 55%

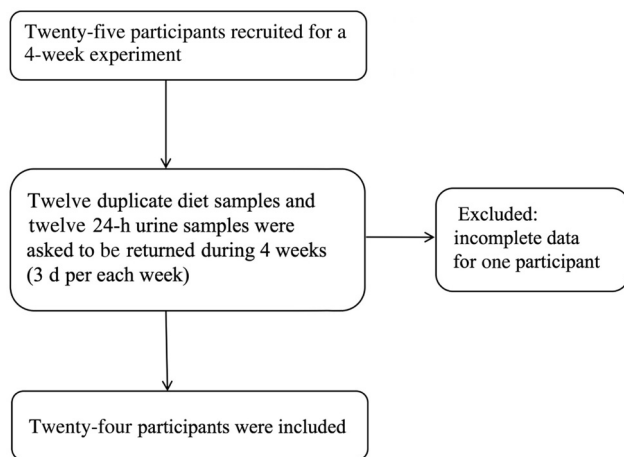


Fig. 1. Flow chart of the study.

Table 1. Descriptive and intra-individual variations on iodine intake and excretion at the individual level* (Means, variances and coefficients of variance %)

Participant	Age (years)	BMI (kg/m ²)	Iodine intake (µg/d)			24-h UIE (µg/d)			Excretion rate			24-h UIC (µg/l)		
			Mean	Variance	CV %	Mean	Variance	CV %	Mean	Variance	CV %	Mean	Variance	CV %
1	21	17.19	241.59	35 520.86	78.01	121.74	5957.92	63.40	0.62	0.18	68.37	88.17	2715.21	59.10
2	21	20.83	263.54	28 707.45	64.29	103.83	1753.33	40.33	0.45	0.03	38.54	136.13	5710.21	55.51
3	19	18.39	250.44	21 012.18	57.88	123.38	2813.56	42.99	0.55	0.03	32.85	113.03	2671.91	45.73
4	21	17.75	244.05	16 081.47	51.96	95.01	1862.17	45.42	0.42	0.02	37.36	133.28	5578.63	56.04
5	22	23.63	277.97	25 582.84	57.54	133.62	3521.52	44.41	0.53	0.03	32.93	102.73	2649.48	50.10
6	21	21.97	305.20	35 217.05	61.49	173.83	4631.07	39.15	0.63	0.03	25.84	96.78	3040.01	56.97
7	21	18.05	246.35	24 564.95	63.62	131.43	3747.11	46.58	0.59	0.04	33.86	149.85	5919.26	51.34
8	22	18.11	277.34	29 582.67	62.02	137.41	4318.10	47.82	0.55	0.03	34.04	132.79	6508.89	60.76
9	21	20.66	249.46	31 314.51	70.94	131.95	3584.58	45.37	0.63	0.07	41.94	131.27	4859.60	53.11
10	22	25.33	289.31	33 005.45	62.80	130.82	3764.52	46.90	0.50	0.02	31.29	127.86	5241.34	56.62
11	22	20.11	271.31	26 016.35	59.45	136.93	8254.26	66.35	0.52	0.05	40.95	126.12	5142.13	56.86
12	21	17.83	265.15	21 006.37	54.66	140.55	2497.75	35.56	0.59	0.04	33.97	112.16	5933.46	68.68
13	21	21.42	289.37	22 167.81	51.45	133.47	3168.63	42.17	0.49	0.02	26.66	82.51	2254.62	57.55
14	21	18.36	269.07	21 676.06	54.72	139.40	5281.70	52.13	0.56	0.05	41.95	94.58	3713.67	64.44
15	22	23.54	278.64	30 719.12	62.90	146.85	5537.69	50.67	0.57	0.03	29.73	119.16	3282.06	48.08
16	20	20.72	290.34	30 111.63	59.77	113.04	3806.81	54.58	0.44	0.05	50.78	80.77	2052.77	56.10
17	23	19.84	287.73	25 903.04	55.94	151.26	6127.60	51.75	0.54	0.01	18.86	92.64	3079.37	59.90
18	24	18.13	233.79	34 380.72	79.31	99.99	2498.18	49.98	0.52	0.03	33.71	90.21	701.63	29.36
19	22	20.75	296.52	31 285.24	59.65	170.61	7641.33	51.24	0.61	0.03	28.65	95.72	1924.10	45.83
20	25	18.52	256.24	27 803.92	65.07	132.20	4250.59	49.32	0.59	0.05	38.50	118.29	4578.76	57.20
21	22	19.52	262.68	30 017.85	65.96	114.29	2637.71	44.94	0.49	0.02	32.34	142.89	7672.65	61.30
22	23	21.76	288.60	31 742.33	61.73	157.16	5177.77	45.78	0.60	0.03	31.24	80.63	2075.37	56.50
23	24	21.51	259.08	39 672.63	76.88	120.08	2333.59	40.23	0.58	0.08	47.58	96.90	2728.13	53.90
24	24	17.36	256.72	27 678.29	64.81	143.11	4229.65	45.44	0.64	0.07	40.28	157.53	5466.66	46.93
Median	22	19.98	267.11	29 145.06	61.88	132.84	3785.67	46.18	0.56	0.03	33.92	112.60	3497.87	56.30
Mean	22	20.05	268.77	28 365.45†	63.05‡	132.58	4141.55†	48.10‡	0.55	0.04†	37.58‡	112.58	3979.16†	55.03‡

UIE, urinary iodine excretion; UIC, urinary iodine concentration.

* Based on twenty-four individual participants and each participant with twelve times experiments.

† Calculated using mean variance among individuals and using ANOVA techniques gave similar results.

‡ Calculated as $\left(\frac{\sum CV^2_{i-24}}{24}\right)^{1/2}$.

Table 2. Descriptive and inter-individual variations on iodine intake and excretion in the population* (Means, variances and coefficients of variance %)

Time	Iodine intake (µg/d)			24-h UIE (µg/d)			Excretion rate			24-h UIC (µg/l)		
	Mean	Variance	CV %	Mean	Variance	CV %	Mean	Variance	CV %	Mean	Variance	CV %
1	169.62	665.41	15.21	101.82	753.86	26.97	0.60	0.02	21.14	70.22	387.02	28.02
2	248.72	591.63	9.78	162.83	1036.83	19.78	0.65	0.01	16.35	131.82	1290.03	27.25
3	143.12	417.51	14.28	106.07	604.92	23.19	0.75	0.04	27.04	84.51	987.50	37.18
4	136.30	265.82	11.96	77.56	310.84	22.73	0.58	0.02	24.10	62.61	382.43	31.24
5	311.08	544.38	7.50	103.18	724.80	26.09	0.33	0.01	24.64	77.17	396.11	25.79
6	232.49	865.12	12.65	91.26	516.61	24.91	0.40	0.01	24.80	84.48	1265.26	42.11
7	167.34	449.43	12.67	92.62	350.69	20.22	0.56	0.01	20.61	76.28	566.53	31.20
8	221.91	1458.04	17.21	97.32	564.67	24.42	0.45	0.02	28.15	81.24	630.61	30.91
9	138.85	729.83	19.46	92.37	723.83	29.12	0.67	0.03	24.22	92.07	1435.35	41.15
10	643.45	3944.10	9.76	241.03	2690.91	21.52	0.37	0.01	18.74	221.57	4287.29	29.55
11	555.79	4790.67	12.45	220.70	2377.81	22.09	0.40	0.01	24.31	173.58	2081.15	26.28
12	256.55	3443.91	22.87	204.22	2651.45	25.21	0.84	0.08	33.81	195.44	4227.54	33.27
Median	227.20	697.62	12.66	102.50	724.32	23.81	0.57	0.02	24.27	84.50	1126.38	31.06
Mean	268.77	1513.82†	14.43‡	132.58	1108.93†	24.00‡	0.55	0.02†	24.39‡	112.58	1494.74†	32.43‡

UIE, urinary iodine excretion; UIC, urinary iodine concentration.

* Based on twelve times experiments and every experiment with twenty-four individual participants.

† Calculated using mean variance among individuals and using ANOVA techniques gave similar results.

‡ Calculated as $\left(\frac{\sum CV^2_{i-12}}{12}\right)^{1/2}$.

of dietary iodine intake was excreted in urine. The mean CV% within individuals for dietary iodine intake, 24-h UIE and 24-h UIC were 63, 48 and 55 %, respectively.

Table 2 presents the descriptions of and inter-individual variations in iodine intake and excretion for the population.

At twelve time points, we measured the iodine contents of diet and urine from twenty-four participants (n 288). At the population level, the CV% for dietary iodine intake, 24-h UIE and 24-h UIC were 14, 24 and 32 %, respectively. Therefore, it was found that the variations in iodine intake and excretion were higher

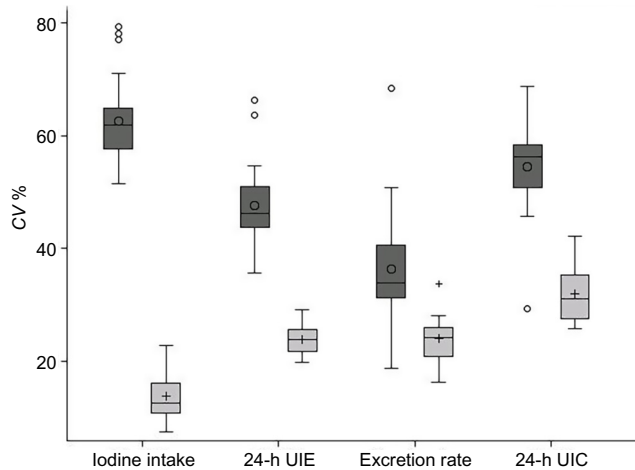


Fig. 2. Comparison of CV% on iodine intake and excretion between individuals and the population. ■, Individuals; □, population. UIE, urinary iodine excretion; UIC, urinary iodine concentration.

intra-individually than inter-individually (Fig. 2). As Fig. 3(a) shows, major intra-individual variation was found in iodine intake, 24-h UIE, 24-h UIC and excretion rate at the twelve time points and no trend was found. On the other hand, the inter-individual variation in the related variables was relatively small and consistent between individuals in a population (Fig. 3(b)).

Table 3 lists the estimated sample size for diet and urine iodine with specific precision ranges at the individual level. With 95% confidence, 588 samples from an individual give a precision range for iodine intake of approximately $\pm 5\%$. For 24-h UIE and 24-h UIC, 328 and 487 samples from an individual are needed, respectively, to estimate iodine excretion within a $\pm 5\%$ precision range. Hence, if the mean 24-h UIC of an individual in 487 measurements was $150 \mu\text{g/l}$, the true 24-h UIC in that individual would be between 143 and $158 \mu\text{g/l}$ with 95% confidence. On the other hand, collecting five samples from an individual to estimate their 24-h UIC would widen the precision range to $\pm 50\%$.

However, the sample size required to assess iodine intake, 24-h UIE and 24-h UIC in a population is smaller than that required for an individual, as presented in Table 4. The results show that if we were to evaluate iodine intake, 24-h UIE and 24-h UIC in a population of the same dietary background to a precision range of 5%, the sample sizes required would be 25, 87 and 148, respectively. When the precision range is higher than 10%, the required sample size of a population is relatively small.

Discussion

Many studies have used UIC to assess iodine status, but few studies have involved the reliability and variability of UIC in assessing the iodine status of a population or an individual^(2,9). In this instance, our study provided a referable set of data by collecting diet and 24-h urine samples twelve times from a small population of twenty-four participants to assess variation in iodine intake and excretion, not just urinary iodine concentrations. We found

that the mean intra-individual variations in 24-h UIC and 24-h UIE were 55 and 48%, respectively. Similar results were also reported by another study with mean CV% of 48% for iodine concentration and of 40% for iodine excretion⁽⁴⁾. However, iodine excretion in our study was measured from a 24-h urine sample, while in the other study, it was estimated from spot urine. Various factors determine UIE and UIC, such as sex, age, socio-cultural and dietary influences, drug interferences, geographical location and season^(10–13). A large variation in individual UIC was also found in other studies^(13,14). A previous study showed that variation in iodine excretion in an individual may follow circadian rhythms⁽¹¹⁾. The authors observed that UIC was lowest at 08.00–11.00 hours and increased progressively between 12.00 and 00.00 hours and that concentrations generally peak 4–5 h after meals. König *et al.* showed that the relatively higher inter-individual CV% for measured 24-h UIE was 41% and that for UIC was 55%⁽¹⁴⁾.

In addition, we analysed the inter-individual and intra-individual variations in iodine excretion, which were 32 and 24%, respectively. Many factors contribute to the variation in iodine excretion between individuals. Indeed, iodine excretion reflects iodine intake shortly before sampling⁽¹⁵⁾, and diet is an important factor affecting iodine intake⁽¹⁶⁾. In particular, the natural iodine content of regularly consumed iodine-containing foods and food items is highly variable^(13,17). Moreover, the bio-availability of iodine varies in different types of food^(18–20). Diet variation among individuals is the main reason for the inter-individual variation, which also results in variation in iodine excretion among different populations^(17,21). The possible reasons for population variation appear to be dietary habits, physiological metabolism, geographical environment and differences in age, weight, height, BMI and overweight status. Further studies are needed to investigate this issue.

We also measured dietary iodine intake using a duplicate-portion technique and analysed the variation in iodine intake from diet. For an individual, eating habits are presumably relatively constant over the long term, but variation still exists in daily dietary intake. A study conducted by Rasmussen *et al.* has also shown day-to-day and within-day variation both in iodine excretion and in iodine intake in an individual⁽²²⁾. For individuals, if there were no dietary restrictions, the change in daily dietary intake would be more significant, particularly when consuming iodine-rich food. These variations exist in individuals and between individuals. In our study, we found that the mean CV% for iodine intake from diet was 63% in individuals and 14% between individuals. The diet variation was obviously higher in individuals compared with that between individuals. This result indicated that populations with similar dietary habits may have relatively similar iodine levels.

In our study, the variations in iodine intake and excretion in a population (inter-individual) were lower than those in an individual (intra-individual). However, these results are still controversial. A study of twenty-two healthy females performed in Switzerland reported that the inter-individual CV% for 24-h UIE and UIC were higher than the individual variation^(14,17). These differences may be due to participants in our study being provided with the same diet in every measurement, which may reduce the inter-individual variation. In addition, we calculated

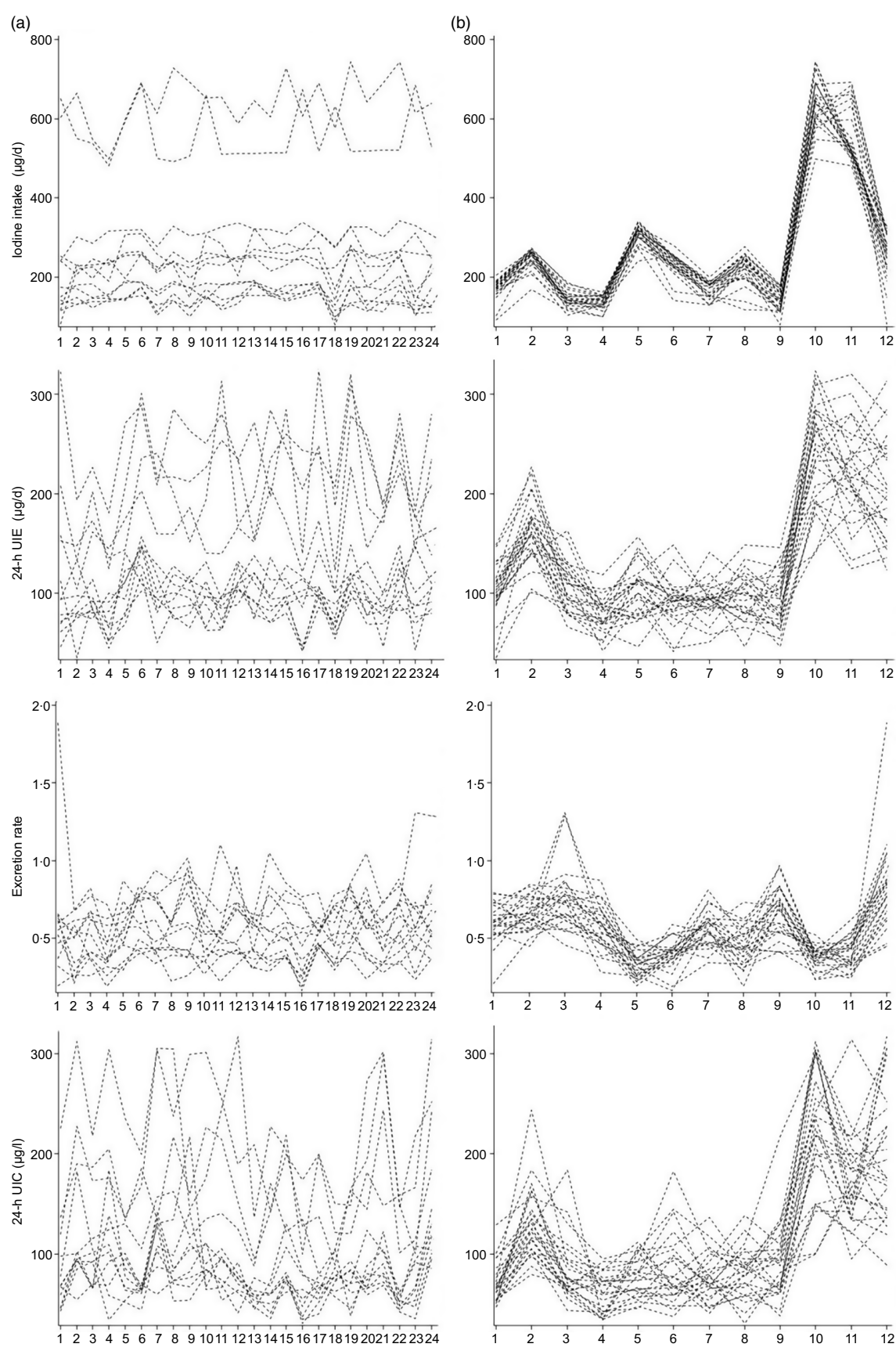


Fig. 3. Trend of variation on iodine intake and excretion in individuals and the population. (a) Intra-individual variations in iodine intake, 24-h urinary iodine excretion (UIE), 24-h urinary iodine concentration (UIC) and excretion rate. (b) Inter-individual variations in iodine intake, 24-h UIE, 24-h UIC and excretion rate.

Table 3. Estimated sample size on iodine intake and excretion with a specified precision range at the individual level* (Medians, lowest and highest variations)

Precision range (%)	Iodine intake (µg/d)			24-h UIE (µg/d)			24 h-UIC (µg/l)		
	Median variation	Lowest variation	Highest variation	Median variation	Lowest variation	Highest variation	Median variation	Lowest variation	Highest variation
±1	14 708	10 169	24 164	8193	4858	16 912	12 177	3311	18 121
±2	3677	2542	6041	2048	1214	4228	3044	828	4530
±5	588	407	967	328	194	676	487	132	725
±10	147	102	242	82	49	169	122	33	181
±20	37	25	60	20	12	42	30	8	45
±30	16	11	27	9	5	19	14	4	20
±40	9	6	15	5	3	11	8	2	11
±50	6	4	10	3	2	7	5	1	7

UIE, urinary iodine excretion; UIC, urinary iodine concentration.

* Calculated with a CI of 95% ($Z = 1.96$). Calculated from $N = (Z \times CV\% / D)^2$, where $Z = 1.96$ for 95% CI, D is the precision range and $CV\%$ based on the variation in individuals. Variation differs between individuals. Number of samples needed to sample in an individual is given for individuals with median, lowest and highest variations.

Table 4. Estimated sample size on iodine intake and excretion with a specified precision range in the population* (Medians, lowest and highest variations)

Precision range (%)	Iodine intake (µg/d)			24 h-UIE (µg/d)			24 h-UIC (µg/l)		
	Median variation	Lowest variation	Highest variation	Median variation	Lowest variation	Highest variation	Median variation	Lowest variation	Highest variation
±1	616	216	2009	2177	1503	3258	3705	2555	6812
±2	154	54	502	544	376	814	926	639	1703
±5	25	9	80	87	60	130	148	102	272
±10	6	2	20	22	15	33	37	26	68
±20	2	1	5	5	4	8	9	6	17
±30	1	1	2	2	2	4	4	3	8
±40	1	1	1	1	1	2	2	2	4
±50	1	1	1	1	1	1	1	1	3

UIE, urinary iodine excretion; UIC, urinary iodine concentration.

* Calculated with a CI of 95% ($Z = 1.96$). Calculated from $N = (Z \times CV\% / D)^2$, where $Z = 1.96$ for 95% CI, D is the precision range and $CV\%$ based on the variation in the population. Variation differs in the population. Number of samples needed to sample in a population is given for individuals with median, lowest and highest variations.

the excretion rate using the ratio of iodine excretion:iodine intake. The variation in excretion rate was also found to be lower among individuals than that in individuals (24 *v.* 36%). Studies have described that renal excretion of iodine remains fairly constant as a proportion of that which has been absorbed⁽²³⁾. It is widely accepted that in healthy adults, over 90% of absorbed iodine is excreted in the urine^(18,24). Nevertheless, our data gave a relatively lower excretion rate of nearly 55%. The absorption of iodine may be affected by iodine intake; thyroid clearance of iodine varies depending on the level of iodine intake and can increase the fraction of absorbed iodine taken up into the thyroid from <10% when iodine is plentiful to over 80% under iodine deficiency⁽²⁵⁾.

Based on the variation we analysed above, we further estimated sample sizes for iodine intake and excretion within a specified precision range. Our data showed that the number of 24-h UIE samples needed to estimate the iodine level in a single individual with 95% confidence within a precision range of ±5% was 328 (87 in a population). However, Rasmussen *et al.* demonstrated that 183 were needed for individuals and 383 were needed for a population⁽²²⁾. A more recent study concluded that 161 24-h urine samples and 165 estimated 24-h UIE were needed to assess individuals' iodine status with 5% precision⁽¹⁴⁾. Our study showed that it takes twenty repeated 24-h urine collections

to determine a single individual's iodine status at a precision of 20%, which is roughly in accordance with earlier findings for estimated UIE and measured 24-h UIE^(4,14). Regarding iodine intake and iodine excretion in a population, our data may provide lower variability because of dietary restrictions. It is generally accepted that UIC from spot samples is a reliable biomarker for recent iodine intake in the population as a whole⁽²³⁾, and at least 500 spot samples are needed⁽²⁶⁾. A precision range of ±5% in a population required 148 samples when using estimated 24-h UIC. In fact, 24-h UIC was more accurate and reproducible than spot UIC in evaluating iodine status in a population⁽³⁾. However, due to the limitations of the operation, it is difficult to use 24-h UIC in a large-scale population survey.

The present study has several limitations. First, the diet of the participants was provided and controlled by the investigators during each measurement, which was likely to reduce the variation compared with that in a regular diet. It has been noted that variation is likely lower in populations with a more monotonous diet⁽¹⁴⁾. Another possible limitation is the generalisation of our results to the general population, since we only included women in the present study. The strengths of our study were that the iodine intake and excretion in our study were accurately determined by double meals as well as by 24-h UIE and 24-h UIC rather than estimation from spot urine samples. In addition,

the inter-individual variations were calculated based on twelve repeated measurements in the same population. In conclusion, our study provides significant reference data for understanding the variation in iodine intake and excretion at the individual and population levels and has implications for sampling in future studies.

Conclusions

Approximately 500 diet samples and 24-h urine samples from an individual, and twenty-five diet samples and 150 24-h urine samples from a population, could estimate iodine intake and excretion at a precision range of $\pm 5\%$ for an individual or a population. The intra-individual variations in iodine intake and excretion were higher than the inter-individual variations, which explains the requirement for more samples for a study on individual participants.

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The authors declare that there are no conflicts of interest.

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