

High iodine intake by preschool children in Miyagi prefecture, Japan

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Abstract

Objectives Standard Tables of Food Composition in Japan 2010 (FCT) remain incomplete for iodine contents. This survey was initiated to develop a method to cope with this shortage and to find daily iodine intake of preschool children in Japan.

Methods Data were available for one-day food intake for 296 3- to 6-year-old children (the total cases). 128 samples (the selected cases) were analyzed by ICP-MS for iodine (the measured values). Iodine intake was also calculated using FCT assuming that iodine contents in missing items were zero (the calculated values).

Results Measured and calculated values for the selected 125 cases (after exclusion of 3 extreme cases) gave geometric means (GM) of 117.6 and 101.8 $\mu\text{g}/\text{day}$. The measured/calculated ratio in GM, $117.6/101.8 = 1.155$, was applied to the calculated values for total 296 cases to

estimate iodine intake (the estimated values). GM for the estimated value was 175.2 $\mu\text{g}/\text{day}$ and it was 8.93 $\mu\text{g}/\text{kg}/\text{day}$ after adjustment for body weight for 296 children. There was no significant difference between boys and girls. **Discussion** The GM values for both the measured and estimated values ($n = 125$ pairs) were 117.6 $\mu\text{g}/\text{day}$. The agreement suggested that the factor employed, 1.155, was proper and adequate. Literature survey suggested that values on a body weight basis were comparable between the children and adults in Japan. The levels were higher than levels in east Asian countries.

Conclusions A correction method was developed for estimation of daily dietary iodine intake. The iodine intake level for preschoolers was comparable to levels for adult population.

Keywords Children · Dietary intake · Food composition tables · Inductively coupled plasma-mass spectrometry · Iodine · Japanese

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Introduction

Iodine (I) is a unique essential element in the sense that insufficient intake among general population may cause endemic goiter whereas excess intake may induce thyroid dysfunction [1]. Administration of potassium iodide has been discussed at the time of nuclear emergency to reduce risk of accumulation of radioactive iodine in thyroid [2–5], but positive association between seaweed consumption and increased risk of thyroid cancer is also discussed [6].

As to be discussed later in detail, it is considered that dietary iodine intake is high among general Japanese population. For example, Nagataki [7] and Muramatsu [8] estimated that dietary intake of iodine was 1.1–1.2 mg/day, and Imaeda et al. [9] estimated 312 and 413 $\mu\text{g}/\text{day}$ for

‘usual intake [10]’ of men and women, respectively. Nevertheless, the quantitative information on dietary iodine intake among Japanese population is still insufficient [11] and the information is further limited on the intake by children [12]. Incomplete listing of iodine contents in food materials in Standard Tables of Food Composition in Japan 2010 (FCT) [13], even after the latest addition to the FCT [14], makes it difficult to obtain correct estimates for children as well as adult population.

The present study was initiated to measure dietary iodine intake among 3- to 6-year-old preschool children, taking advantage of recently published food intake records [15–17]. For this purpose, two methods were employed. One is instrumental analysis using inductively coupled plasma-mass spectrometry (ICP-MS) after alkali digestion. ICP-MS [18] has been gaining popularities in recent years as a tool to measure iodine in various biological materials including foods [19–23]. The other is FCT-based estimation. The latest version (2010 version) of Japanese FCT (in combination with the latest additions and corrections) lists up, for the first time in a series of the FCT publications, iodine contents in various (although not all) food items consumed by Japanese population [13, 14]. The iodine content values will make it possible to estimate dietary intake of iodine using the FCT.

The results of the analyses will be presented in this article to show distribution pattern of daily iodine intake, and to report dietary intake level of iodine among Japanese children. A procedure will be proposed in the present article to estimate daily iodine intake from FCT-based calculated values. The estimated daily iodine intake for preschoolers will be presented in comparison with levels for adult population in Japan and east Asian countries.

Materials and methods

Ethical issues

The study protocol was approved by the Ethics Committee of Miyagi University, Japan. Each and all of guardians of the participating children provided informed consents in writing.

Study participants and food duplicate collections

The participants were apparently healthy 160 boys and 136 girls (296 children in total) from 15 kindergartens in Miyagi prefecture in north-eastern Japan. The children were 3–6 years old, and their body weights were measured and recorded. The demographic characteristics were described in detail previously [15–17], and are summarized in Table 1. Nutrient intakes were also reported in these

Table 1 Demographic parameters

Sex	Age	Total group				Selected group ^a No.
		No.	Bodyweight (kg)			
			AM	Min.	Max.	
Boys	3	9	16.6	15.1	18.1	1
	4	30	18.2	13.3	27.0	16
	5	74	19.9	14.0	33.9	25
	6	47	23.2	15.6	35.2	29
	Sum	160				71
Girls	3	4	14.2	13.1	15.5	1
	4	32	18.0	13.5	27.3	14
	5	60	19.8	14.9	36.3	24
	6	40	20.7	15.6	28.1	18
	Sum	136				57
Total		296				128

^a Selected for instrumental analysis for iodine intake; out of the 128 cases, 3 cases were excluded as extreme cases

articles [15–17]. Each of the children submitted 24-hour food duplicate samples [24]. Foods collected from the food duplicate samples were identified in reference to the items in the FCT [13, 14]. The item number and the weight of each food item were recorded following the procedures detailed previously [15–17]. Each of the food duplicate samples was then homogenized using a blender [15–17].

Instrumental analysis for iodine (measured values)

Due to limitations in analysis capacity, it was not possible to analyze all food duplicate homogenate samples. Thus, 6 kindergartens (with 128 attending children) were identified out of the 16 kindergartens by random selection, and the samples from the 128 children were subjected to the instrumental analysis. The analyses were conducted after the study of Fecher et al. [18] and Ministry of Education, Culture, Sports, Science and Technology, Japan [25]. In practice, a portion of the homogenate (2.5 g) was wet-digested under alkaline condition with 50 ml of 0.5 % tetramethylammonium hydroxide (TMAH) by heating overnight (8–12 h) at 60 °C in a polypropylene vessel with a gas-tight screw cap. The digest was subjected to instrumental analysis after centrifugation to remove solid materials.

The instrument used was an inductively coupled plasma-mass spectrometer (Model: 7700×) from Agilent Technologies, Santa Clara, California, USA. The instrument was operated under ‘no gas mode’ (with no use of collision/reaction gas), and tellurium 125 (or tellurium 128) was used as an internal standard. Addition of tellurium internal standard solution was carried out by means of on-line method.

Under the operation conditions, the recovery in comparison with two reference materials of NIST 1548a (Reference value for I; 0.759 ppm) and NIES No. 27 (Reference value for I; 1.9 ppm) was 0.62 ppm (82 %) and 1.84 ppm (97 %), respectively. The relative standard deviations ($n = 10$) were 2.6 and 3.8 %. The LOD and LOQ were estimated to be 0.1–0.3 ppb and 0.3–1 ppb, respectively.

Food composition table-based calculation of the dietary iodine intake (calculated values)

The Standard Tables of Food Composition in Japan 2010 (FCT [13], supplemented by the latest additions and corrections [14]), contain 1,878 food items, of which iodine content data are available for 518 food items (27.6 %). The coverage by food group vary with a high of 51.4 % for Group 5 (Nuts and seeds) and a low of 16.0 % for both Group 11 (Fishes and shellfishes) and Group 12 (Meats). For Group 9 Algae, the expected leading dietary iodine source for Japanese [8, 9], the iodine content values were available for 18 items in a total of 47 items (the coverage; 38.3 %).

The daily iodine intake was calculated from food weights and iodine contents given in the FCT [13, 14]. In practice, iodine contents were assumed to be zero in food items for which no values were given for iodine contents.

Estimation of daily dietary iodine intake (estimated values)

As detailed above, the iodine contents are not available for many food items in current FCT [13, 14], and assumption of zero iodine content for food items (for which no iodine content values are given) may result in under-estimation. As to be detailed later (also see the footnote under Table 2), the geometric mean for the measured values was 117.6 $\mu\text{g}/\text{day}$ in the 125 selected cases and that for the calculated values was 101.8 $\mu\text{g}/\text{day}$. The difference between the two values was thought to be due to the missing iodine. The ratio of the measured value GM to the

calculated value GM (or $117.6/101.8 = 1.155$) was employed to estimate dietary iodine intake from the calculated value, i.e.,

The estimated value = The calculated value \times 1.155.

Reagents

The iodine standard solutions were prepared by dissolving potassium iodide (Wako Pure Chemicals, Osaka, Japan) in 0.5 % TMAH aqueous solution. The standard reference material of typical diet (NIST1548a) was obtained from the National Institute of Standard and Technology (Gaithersburg, USA). The reference material of ‘typical Japanese foods’ (NIES No. 27) was from the National Institute of Environmental Sciences, Japan (Tsukuba, Japan). TMAH of high purity (with iodine impurity $<200 \text{ ng/l}$) was obtained from Tama Chemicals, Kawasaki, Japan.

Statistical analysis

As to be described later, the daily intake amount of iodine from diets distributed log-normally. Thus, iodine amount data were logarithmically converted before statistical evaluation by Student’s t test, etc. Geometric means (GM) and geometric standard deviations (GSD) together with medians (MED) were taken as representative parameters of the distributions. When necessary, two-way analysis of variance (followed by Scheffe’s test) and Smirnov’s test for extreme values [25] were employed.

Results

Distribution patterns of the amounts of iodine intake among 125 selected cases

Measured values were available for 128 cases initially. Application of Smirnov’s test for extreme values identified three cases as extremes to be excluded. Thus, further statistical analyses were conducted with remaining 125 cases. Analyses for distribution patterns with the 125

Table 2 Comparison of calculated, estimated and measured values among selected 125 cases

	No.	Measured values			Calculated values				Estimated values			
		GM	GSD	MED	GM	(%) ^a	GSD	MED	GM	(%) ^a	GSD	MED
Boys	68	110.1	2.48	81.4	95.4		2.51	89.6	110.2		2.51	103.5
Girls	57	127.3	2.25	109.5	110.0		2.59	93.5	127.2		2.59	108.0
Total	125	117.6	2.37	96.3	101.8	(86.5)	2.54	90.9	117.6	(100.0)	2.54	105.1

GMs and MEDs are in $\mu\text{g}/\text{day}$. GSD s are dimensionless. The ratio of GM for measured values over GM for calculated values: $(117.6/101.8) = 1.155$

^a Percentage of GM values over GM for measured values

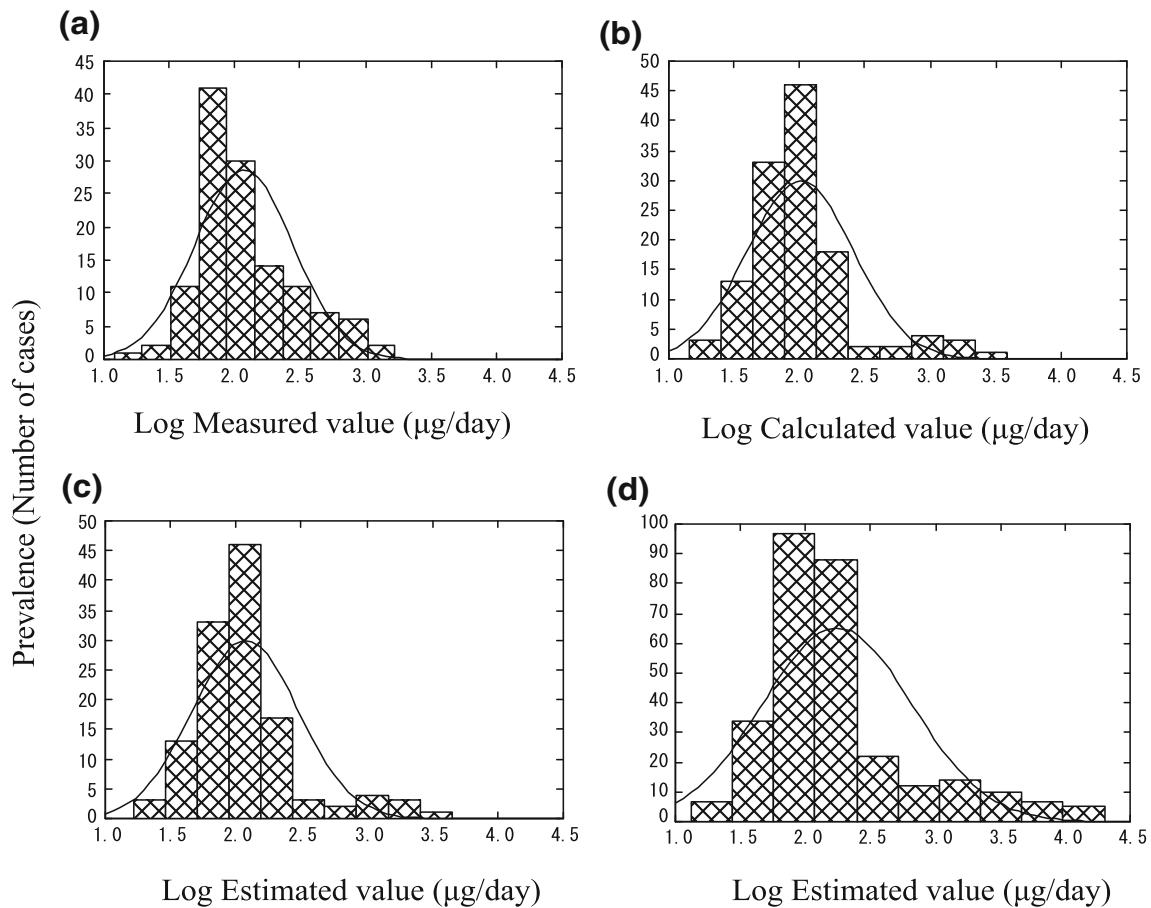


Fig. 1 Distribution histograms of **a** measure values **b** calculated values and **c** estimated values (after logarithmic conversion) for 125 selected cases. **d** shows the distribution of a total 296 cases. The

horizontal axes show the values after logarithmic conversion; the values are in µg/day. The curves show normal distribution

cases (Fig. 1) showed that both measured and calculated values distributed approximately log-normally (Fig. 1a, b and c).

Comparison of measured values and calculated values, and development of a method for estimated values

Analysis for relation between 125 pairs of logarithm of the measured values and that of the calculated values (Fig. 2) revealed that the pairs correlated significantly with a correlation coefficient of 0.442 ($p < 0.01$ for the coefficient). Nevertheless, GM for calculated values (101.8 µg/day) was smaller than the GM for measured values (117.6 µg/day) ($p < 0.01$ by paired t test); the former was 86.5 % of the latter. When the ratio of $117.6/101.8 = 1.155$ was applied to the calculated values as the compensation for missing iodine items, the application resulted in the GM of 117.6 µg/day, which is the same with the GM for the measured values (117.6 µg/day) (Table 2) to suggest that the estimation was adequate.

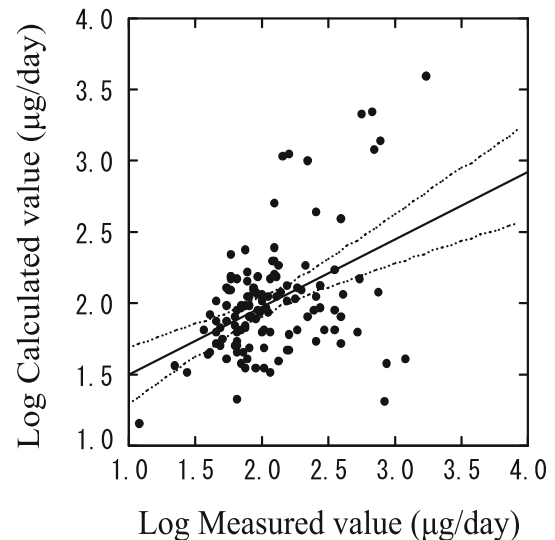


Fig. 2 Correlation between 125 pairs of measured values and calculated values after logarithmic conversion. Each dot shows one case and the line in the middle is a calculated regression line of $Y = 1.02 + 0.48X$ ($r = 0.442, p < 0.01$), where X and Y are log measured and calculated values (both in µg/day), respectively. The dotted curves on both sides of the regression line show the 95 % limit of the means

Table 3 Estimated daily iodine intake of 296 children; as observed and as corrected for body weight

Age	Boys			Girls			Total		
	No.	GM	MED	No.	GM	MED	No.	GM	MED
(A) As observed (unit: μg iodine/day)									
3 + 4 years	39	257.7	128	36	191.1	141	75	223.2	137
5 years	74	181.7	133	60	142.8	114	134	163.1	126
6 years	47	160.7	138	40	156.2	108	87	158.6	123
Total	160	190.9	136	136	158.4	116	296	175.2	127
(B) As corrected for body weight (unit: μg iodine/kg body weight/day)									
3 + 4 years	39	14.64	8.13	36	11.00	7.60	75	12.76	7.66
5 years	74	9.25	6.80	60	7.34	5.93	134	8.34	6.12
6 years	47	7.02	6.08	40	7.61	4.80	87	7.29	5.72
Total	160	9.54	6.64	136	8.26	6.05	296	8.93	6.28

Daily iodine intake by age groups

The daily iodine intake was estimated for a total of 296 cases by application of the factor of 1.155 to each of the calculated values, and the estimated values thus obtained were classified by sex and age of the children. As the number of cases of 3-year-old girls was as small as 4, two groups, 3- and 4-year olds, were combined both for boys and for girls (the top half in Table 3). The GM for the estimated iodine intake was 191 $\mu\text{g}/\text{day}$ for boys, 158 $\mu\text{g}/\text{day}$ for girls, and 175 $\mu\text{g}/\text{day}$ for the combination. The intake tended to decrease as a function of age. Application of two-way analysis of variance taking sex and age as two independent variables and log-estimated iodine values as a dependent variable, however, showed that the decrease was statistically insignificant ($p > 0.10$).

Daily iodine intake as adjusted for body weight

It was evident that children became heavier as they grew (Table 1). When the iodine intake was adjusted for body weight, the GM iodine intake was 8.93 $\mu\text{g}/\text{kg}/\text{day}$ for total children (9.54 $\mu\text{g}/\text{kg}$ body weight/day for boys and 8.26 $\mu\text{g}/\text{kg}$ body weight/day for girls) (the bottom half in Table 3). Two-way analysis of variance followed by post hoc test (Scheffe) taking sex (in two categories of boys and girls) and age (in three categories of 3 + 4 years, 5 years and 6 years of age) as two independent variables and log (estimated iodine value/kg body weight/day) as a dependent variable disclosed that the difference between boys and girls was insignificant ($p > 0.10$). The difference between the 3 + 4 year-old group and the 6-year-old group was significant ($p < 0.05$) whereas no difference was observed between the 3 + 4 year-old group and the 5-year-old group or between the 5-year-old group and the 6-year-old group ($p > 0.10$).

Discussion

It has been reported that dietary intake of iodine in Japan is among the highest groups in the world [27–30]. Nevertheless, information is still insufficient for adult population [11] and further scarce for children [12].

The present analysis showed that the iodine intake by 3- to 6-year-old children is 175 $\mu\text{g}/\text{day}$ as GM and 127 $\mu\text{g}/\text{day}$ as MED (the top half in Table 3). When adjusted for body weight, GM and MED values are 8.93 and 6.28 $\mu\text{g}/\text{kg}/\text{day}$, respectively (the bottom half in Table 3). The factor of 1.155 to convert FCT-based calculated values to the estimated daily intake was considered to be proper and adequate, because the conversion gave the same GM for the estimated values (e.g., 117.6 $\mu\text{g}/\text{day}$ for boys and girls combined) to the GM for the calculated values (117.6 $\mu\text{g}/\text{day}$) (Table 2). Comparison with the iodine intake recommended by the Ministry of Health, Labour and Welfare, Japan [31] for 3- to 6-year-old children (Table 4) shows that the intake observed among the children is in excess of recommended dietary allowance (RDA; 60–75 $\mu\text{g}/\text{day}$ or 3.4–3.7 $\mu\text{g}/\text{kg}/\text{day}$) but well below the allowable upper limit (UL) of 350–500 $\mu\text{g}/\text{day}$ or 21.6–22.7 $\mu\text{g}/\text{kg}/\text{day}$.

Table 4 Recommended iodine intake

Age	Unit	EAR	RDA	UL	BW
3–5 years	$\mu\text{g}/\text{day}$	45	60	350	16.2 kg
	$\mu\text{g}/\text{kg}/\text{day}$	2.78	3.70	21.60	
6–7 years	$\mu\text{g}/\text{day}$	55	75	500	16.2 kg
	$\mu\text{g}/\text{kg}/\text{day}$	2.50	3.40	22.73	

The same value for both boys and girls

EAR estimated average requirement, RDA Recommended dietary allowance, UL Allowable upper limit, BW Standard body weight

Values are cited from Ministry of Health, Labour and Welfare, Japan [31]

In the following discussion, efforts were made to compare iodine intake on the body weight basis because most of the existing data are for adult population. Findings in selected reports on Japanese population are summarized in Table 5. For example, Tsukada et al. [32] reported their FCT-based observation of 339 $\mu\text{g}/\text{day}$ for adult Japanese or 5.94 $\mu\text{g}/\text{kg}/\text{day}$ when adjusted for body weight. Imaeda et al. [9] estimated median (usual day [10]) iodine intake of 312 and 413 $\mu\text{g}/\text{day}$ for men and women with average body weights of 62.0 and 52.2 kg, respectively, or 5.0 and 7.9 $\mu\text{g}/\text{kg}/\text{day}$. Nagataki [7] and Muramatsu [8], in contrast, gave much greater estimates of 1,200 and 1,100 $\mu\text{g}/\text{day}$, which are equivalent to 19–20 $\mu\text{g}/\text{kg}/\text{day}$. The MED by the present study, 6.28 $\mu\text{g}/\text{kg}/\text{day}$, is essentially the same with the MED of 6.60 $\mu\text{g}/\text{kg}/\text{day}$ by Fuse et al. [12] when adjusted for body weight. Thus, the iodine intake by children appears to be comparable to the levels for adult Japanese.

In east Asia, Kim et al. [35] in Korea estimated that the AM iodine intake by adult Koreans was 450.9 and 504.6 $\mu\text{g}/\text{day}$; the GM values were 313.7 and 336.8 $\mu\text{g}/\text{day}$ when GM values were estimated from AM to ASD using the moment method [36], or 5.0 and 7.9 $\mu\text{g}/\text{kg}/\text{day}$ with further consideration of 62.0 and 52.2 kg for average body weight of men and women, respectively. Kim et al. [37] reported 376.5 ± 281.7 $\mu\text{g}/\text{day}$ as an AM \pm ASD iodine intake by adult Korean men with normal thyroid function. The GM value is 301.5 $\mu\text{g}/\text{day}$ when the moment method was applied, or 4.3 $\mu\text{g}/\text{kg}/\text{day}$ when 70 kg was taken into account for average body weight of 40-year-old men [38]. In Shanghai, China, where table salt was iodized at the level of 29.5 mg/kg, median urinary iodine concentration was 146.7 $\mu\text{g}/\text{l}$ [39], which suggests an iodine intake of 3.4 $\mu\text{g}/\text{kg}/\text{day}$, when the estimation equation of urinary iodine concentration (UIC: $\mu\text{g}/\text{l}$ in 24-hour urine sample) to daily iodine intake (DII in $\mu\text{g}/\text{day}$), $\text{DII} = \text{UIC} \times 0.0235 \times \text{body weight (kg)}$ [40], is applied. The practice of table salt iodization suggests that there is a risk of insufficient dietary iodine intake. Two urinary iodine concentrations of 72.27 and 57.23 $\mu\text{g}/\text{l}$ were cited by Zou et al. [39] for urban and suburban population in the year 1995. The application of the equation above gave 1.0 and 1.3 $\mu\text{g}/\text{kg}/\text{day}$, respectively. A recent report from China states that 24 and 35 % of the men and women, respectively, had thyroid nodules, an indicator of insufficient iodine intake [41] in areas where table salt was not iodized, suggesting that iodine intake was insufficient among general population even in coastal areas in China. Similarly, a publication on population in two regions in Nepal [42] reported low iodine intake levels; the GM levels were 3.14 and 2.62 $\mu\text{g}/\text{kg}/\text{day}$ for men and women in one region, and 3.02 and 2.07 $\mu\text{g}/\text{kg}/\text{day}$ in the other when body weights of 65 and

53 kg were assumed for body weights of men and women, respectively [38].

The difference in iodine intake in China and Nepal from that in Japan and Korea may be due to different dietary habits in consumption of iodine-rich seaweed in daily life. With this regard, Suzuki and Tamura [43] measured UID in subjects after administration of seaweed-rich (i.e., high-iodine) or seaweed-deleted (i.e., low-iodine) foods and found that UID varied in parallel to dietary iodine intake. The results are interesting in the sense that this observation appears to give direct evidence that seaweed is the major source of iodine. Unfortunately, these authors did not use alkali condition for digestion of urine samples and the possible loss of iodine from the digest cannot be ruled out. Thus, the study results may be evaluated only semi-quantitatively.

There are several limitations in the present study. First of all, children studied were all from one prefecture of Miyagi although Japan consists of 47 prefectures. It is quite conceivable that food intake varies subject to local food habits. A nation-wide survey is apparently warranted.

The application of a conversion factor of 1.155 (Table 2) to estimate daily iodine intake from the calculated values which are based on the current FCT; the FCT is still incomplete with regard to iodine content information. The present analysis suggests that the conversion factor is proper and adequate (Table 2). Nevertheless, further efforts are apparently necessary to develop better estimation procedures.

To establish the factor, three cases were excluded as extreme values in the statistical analysis. A preliminary analysis of the food records revealed that the calculated values were substantially greater than the measured values in two children who took ‘naga-kombu’, a type of seaweed, and reverse was the case in the third child who took ‘hi-jiki’, another type of seaweed. It remained unclear; however, if the extreme values were associated with seaweed intake. Analyses for causative factor(s) were apparently warranted.

In conclusion within the limitations cited above, a method was developed to estimate dietary iodine intake (for all food items) from FCT-based calculated values despite the limitation that the iodine content data in the existing FCT do not cover all food items. Based on the method, the iodine intake for 3- to 6-year-old children in Miyagi prefecture, Japan, was 175 $\mu\text{g}/\text{day}$ with no difference between boys and girls. The iodine intake of the children was at the levels comparable to that of reported levels for adult Japanese population, when adjusted for body weight. Literature survey suggested that the levels both for children and adults in Japan may be somewhat higher than the intake in Korea, and substantially higher than the levels in China and Nepal.

Table 5 Daily dietary intake of iodine, reported in selected recent publications for Japanese

Reference	Subjects		Iodine intake				Notes							
	No. Men or boys	Women or girls	μg/day		μg/kg/day									
			No. Average age	No. Average age	Men or boys	Women or girls		Men or boys	Women or girls					
The present study	160	3–6	136	3–6	296	3–6	GM	191	158	175	9.54	8.26	8.93	For details, see the materials and Methods section
7 Nagataki							MED	136	116	127	6.64	6.05	6.28	For details, see the materials and methods section
8 Muramatsu							Unknown			1,200			20.3	Estimation based on kelp intake; 59 kg body weight was assumed [30].
9 Imaeda et al.	18	45 (62.0 kg)	80	46.7 (52.2 kg)			MED	312	413	1,100	5.03	7.82	18.5	Review; 59 kg body weight was assumed [30]. 62.4 and 52.2 kg were reported for average body weights of men and women, respectively. Food items were replaced by similar ones as necessary when iodine contents were not given in FCT.
12 Fuse et al.					317	6–12	MED						6.60	Estimated by the present authors from median urinary iodine concentration of 281.6 μg/l
32 Tsukada et al.					760	21	MED			339			5.94	Based on the food composition tables, Japan, 2010; an average body weight of 57 kg was assumed for men and women in combination [30].
33 Fuse et al.			31	45.7			GM		880				16.6	Iodine-specified food intake questionnaire; 53 kg body weight was assumed for adult women [30].
34 Fuse et al.	129	48	93	48.8			MED	606	540		8.60	9.98		Iodine-specified food intake questionnaire; 65 and 53 kg body weights were assumed for adult men and women, respectively [30].

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Conflict of interest The authors declare that they have no conflicts of interest.

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