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Iodine intake from brown seaweed and the related nutritional risk assessment in Koreans

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ABSTRACT

BACKGROUND/OBJECTIVES: Although iodine is essential for thyroid hormone production and controls many metabolic processes, there are few reports on the iodine intake of the population because of the scarcity of information on the iodine content in food. This study estimated the iodine intake of Koreans from brown seaweed, the major source of iodine in nature.
SUBJECTS/METHODS: The dietary intake data from the recent Korea National Health and Nutrition Examination Survey (2016–2021) and the iodine content in brown seaweed were used for the estimation. Nationwide brown seaweed samples were collected and prepared using the representative preparation/cooking methods in the Koreans' diet before iodine analysis by alkaline digestion followed by inductively coupled plasma mass spectrometry.
RESULTS: The mean (± SE) iodine intake from sea mustard was 96.01 ± 2.36 μg/day in the Korean population. Although the iodine content in kelp was approximately seven times higher than that in sea mustard, the mean iodine intake from kelp (except broth) was similar to that of sea mustard, 115.58 ± 7.71 μg/day, whereas that from kelp broth was 347.57 ± 10.03 μg/day. The overall mean iodine intake from brown seaweed was 559.16 ± 13.15 μg/day, well over the Recommended Nutrient Intake of iodine for Koreans. Nevertheless, the median intake was zero because only 37.6% of the population consumed brown seaweed on the survey date, suggesting that Koreans do not consume brown seaweed daily.
CONCLUSION: The distribution of the usual intake of iodine from brown seaweed in Koreans would be much tighter, resulting in a lower proportion of people exceeding the tolerable upper intake levels and possibly a lower mean intake than this study presented. Further study evaluating the iodine nutriture of Koreans based on the usual intake is warranted. Nevertheless, this study adds to the few reports on the iodine nutriture of Koreans.

Keywords: Iodine intake; brown seaweed; nutritional risk; usual intake

INTRODUCTION

The World Health Organization has stated that iodine deficiency is the single most important preventable cause of brain damage [1]. Iodine is an essential trace element that is indispensable for producing thyroid hormones and controlling many metabolic processes [2]. Even though iodine is usually taken up with food, agricultural products that take a large

Conflict of Interest
The authors declare no potential conflicts of interests.

Author Contributions
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portion of the human diet do not provide appreciable amounts of iodine owing to the low iodine levels in the soil. On the other hand, fish, shellfish, and seaweed are good sources of iodine, but they do not contribute significantly to the iodine intake of people in countries other than some Asian countries, including China, Japan, and Korea. Seaweed comprises a good portion of people's usual diet in these countries due to tradition, palatability, affordability, versatility, and longer shelf-life (dried form).

Seaweed is not a popular food item in many countries. Therefore, the food composition tables from those countries usually do not include seaweed, and the iodine content in food is not readily available. This appears to be one of the reasons why some researchers use the urinary iodine levels instead of dietary iodine intake to monitor the iodine nutrition status. In a recent paper published in the journal '*Thyroid*,' Ittermann *et al.* [3] established the first standardized map of the iodine status in Europe using standardized urinary iodine concentration (UIC) data from a large number of studies. They concluded that iodine deficiency still exists in Europe, and adults and pregnant women are at particular risk. Among the countries they studied, Germany showed the highest inadequacy for iodine intake, and a similar finding was also reported in the German Federal Institute for Risk Assessment (BfR) FAQ [2] with suggestions for a good iodine intake. Germany has experienced prolonged iodine deficiency. Hence, a tolerable upper intake level (UL) of 500 μg/day for adults was set conservatively in Germany with the concern of the potential higher sensitivity to iodine among the elderly in particular and developing an over-function of the thyroid gland as a result of excessive iodine intake.

In contrast, in countries with frequent seaweed consumption in the usual/common diet, Japan and Korea for example, the UL for adults was set at a much higher level of 3,000 and 2,400 μg/day, respectively [4,5]. Another UL, 1,100 μg/day for adults, was set in Australia and New Zealand [6] and Canada and the United States [7] because different populations with different iodine nutritional status may have different metabolism and iodine requirements [8].

In a recent study estimating the dietary iodine intake of Koreans based on a total diet study (TDS), Lee *et al.* [9] reported that 77.3% of the total iodine intake of Koreans was from the seaweed group, laver, sea mustard, and kelp (sea tangle). The latter two items are called 'brown seaweed' with a seven- and 80-fold higher iodine content than laver, respectively. This might have formed the background of the action taken by the Australian government (Quarantine and Inspection Service under the Department of Agriculture, Fisheries and Forestry; DAFF), listing dried brown seaweed as one of the 'risk foods' in the Imported Food Control Order 2019 based on the 'Imported food risk statement' on iodine in brown seaweed provided by the Food Standards Australia New Zealand (FSANZ).

This study estimated the iodine intake of Koreans from dried brown seaweed of the *Phaeophyceae* class, namely sea mustard and kelp, using the food intake data from the recent Korea National Health and Nutrition Examination Survey (KNHANES) and the iodine content in the representative brown seaweed samples prepared using the representative preparation/cooking methods used in the daily diet of Koreans and analyzed at a Korean government certified lab.

SUBJECTS AND METHODS

Selection of the representative preparation/cooking methods used in the usual and common dishes, which include sea mustard, kelp, or both as ingredients in the diet of Koreans

Dietary intake data from the 7th KNHANES (2016–2018) and the 8th KNHANES (2019–2021) were merged into one dataset with equal weights for each of the six years. The 7th KNHANES data was used in addition to the recent 8th KNHANES data to attenuate the possible changes in diet due to the coronavirus disease 2019 pandemic in 2020–2021. The food intake data of 40,166 subjects aged one year and older were included in the data set and used in selecting representative preparation/cooking methods commonly used for sea mustard and kelp in the Korean diet.

In the nutrition survey part of KNHANES, very detailed information on the dietary habits of the population at the individual level was collected, and the results are publicly available through the KNHANES raw data depository [10]. KNHANES was approved by the Institutional Review Board of the Korea Disease Control and Prevention Agency (IRB No. 2018-01-03-P-A, 2018-01-03-C-A, 2018-01-03-2C-A, and 2018-01-03-3C-A) and written informed consent was obtained from all the participants. Based on the dietary intake data from the one day 24-h recalls, several preparation/cooking methods were identified for brown seaweed, as listed in **Table 1**. Following the principles and rules of 'more and frequent use' in selecting preparation/cooking methods [11], this study selected representative preparation/cooking methods covering at least 90% of the total intake of each brown seaweed. The results are as follows: boiled, soaked, and fried for dried kelp, soaked and boiled and soaked for dried sea mustard, and boiled for kelp broth.

Collection of brown seaweed samples available in markets in Korea

The representativeness of the brown seaweed samples was secured by collecting dried sea mustard and dried kelp samples in July 2023 from nine mega-markets in nine metropolitan cities (Seoul, Inchon, Suwon, Kwangju, Daejeon, Cheongju, Busan, Daegu, and Ulsan) representing three regions (north-western, south-western and eastern region) nationwide according to the collection scheme suggested for the Korean Total Diet Study [12]. The iodine content can vary depending on the part of the seaweed. Therefore, several packages

Table 1. Preparation/cooking methods used for brown seaweed in the 7th and 8th KNHANES

Food	Preparation/cooking method used	Number of relevant dishes	Mean intake (g/person/day)	Proportion in each seaweed intake (%)
Sea mustard, dried	Soaked & boiled	48	0.6005	78.3
	Soaked	19	0.0973	12.7
	Soaked & stir-fried	2	0.0685	8.9
	Fried	1	0.0009	0.1
	Total	70	0.7673	100.0
Kelp, dried	Boiled	115	0.0327	42.9
	Soaked	15	0.0291	38.2
	Fried	1	0.0118	15.5
	Soaked & stir-fried	12	0.0025	3.3
	Soaked & steamed	3	0.0000	0.0
	Total	146	0.0761	100.0
Kelp broth, liquid	Boiled	260	22.4514	98.9
	As is	17	0.2230	1.0
	Stir-fried	23	0.0250	0.1
	Baked	2	0.0007	0.0
	Total	302	22.7001	100.0

KNHANES, Korea National Health and Nutrition Examination Survey.

of different forms/parts were purchased for each brown seaweed and mixed into individual composites for each city in equal portions prior to the preparation/cooking of seaweed to a 'table ready' state for iodine analysis. Duplicate composites were made for samples from each city to increase the number of samples for iodine analysis.

Preparation of brown seaweed samples to a 'table-ready' state for analysis

Eighteen composites were made for each brown seaweed to make 144 'table-ready' state samples for analysis with different preparation methods (three methods for sea mustard and five methods for kelp). Preparation was performed according to the 'Guide for Sample Preparation for the Korean Total Diet Studies' [12] using the representative preparation/cooking methods selected for each brown seaweed, as shown in the **Supplementary Table 1**. Stainless kitchen utensils (e.g., bowls, pots, knives, and spoons) and silicon spatulas were used to prevent contamination or unintended loss of iodine during preparation. The samples were weighed at each preparation step to monitor the weight changes and secure the dilution factors for the final calculation.

The prepared samples were cooled to room temperature and pulverized (dry samples) or homogenized (wet samples) to produce sample aliquots for analysis. Four 30–40 g aliquots were prepared for each sample for the chemical analysis and stored at −20°C.

Analysis of chemicals

The Korea Health Functional Food Institute was engaged to analyze all 144 samples in triplicate for iodine content using the Ministry of Food and Drug Safety (MFDS) accredited method of alkaline digestion followed by inductively coupled plasma mass spectrometry (ICP/MS). This method is the authentic method stated in the Food Code in Korea [13] and was also used in the 1st Korean Total Diet Study for iodine analysis [9,14]. The limit of detection (LOD) and limit of quantification (LOQ) for this analysis were 0.014 and 0.04 mg/kg, respectively. When necessary, the 4th analysis was performed on the same samples.

Estimation of iodine intake from brown seaweed and statistical analysis

The food intake data from 6 yrs of KNHANES were merged into a single dataset by giving equal weights to each year, 1:1:1:1:1:1, and analyzed using the weights assigned to the sample individuals who represented the Korean population in KNHANES. The iodine intake was estimated by multiplying the brown seaweed intake and the corresponding iodine content at the individual level. The Statistical Analysis System (SAS) 9.4 (SAS Institute, Cary, NC, USA) was used for statistical analysis.

RESULTS

Iodine content in the sea mustard samples according to the preparation/cooking method

The mean (± SD) iodine content in sea mustard calculated from the values in the 'as is' samples was 204.09 ± 39.31 mg/kg, and the mean for the samples from each of the cities ranged from 155.58 ± 12.15 mg/kg (Incheon) to 257.01 ± 25.41 mg/kg (Daejeon) (**Fig. 1**).

The mean iodine content in sea mustard calculated from the values in the 'soaked' samples and converted to a dry weight basis was significantly lower, 138.98 ± 35.11 mg/kg, ranging from 99.86 ± 14.58 mg/kg (Suwon) to 184.34 ± 22.91 mg/kg (Daejeon). As shown in **Fig. 1**,

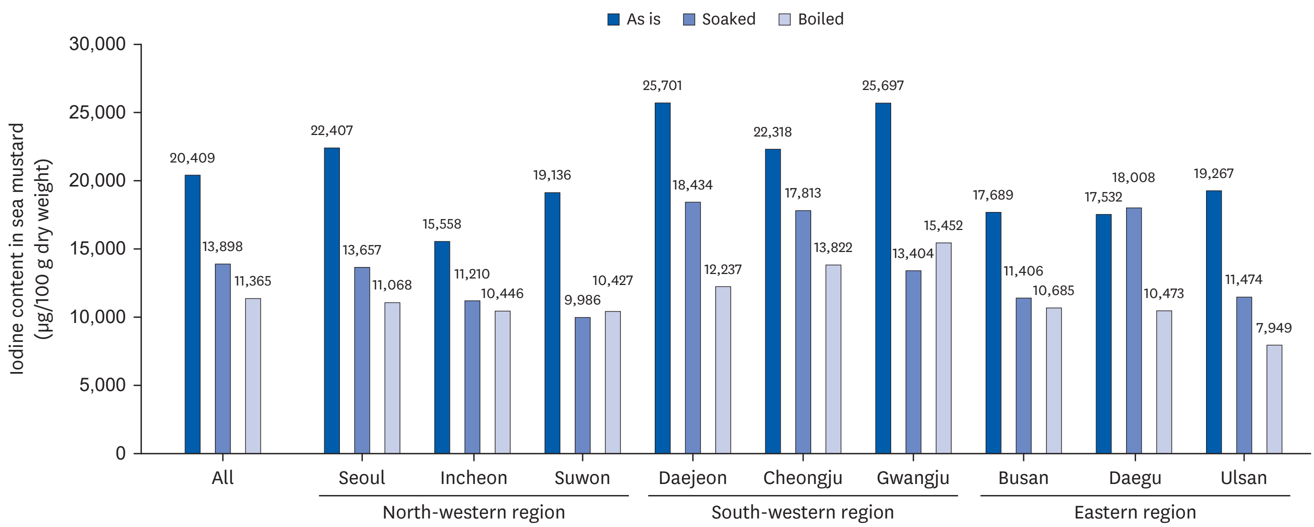

Fig. 1. Iodine content in sea mustard (μg/100 g dry weight) according to the city and preparation method.
The iodine content in the prepared samples was converted to the corresponding value in dried sea mustard.
As is, dried sea mustard; soaked, dried sea mustard soaked in water for 60 min and drained; boiled, soaked and drained sea mustard boiled for 15 min as explained in the **Supplementary Table 1**.

the iodine content in sea mustard decreased after 60 min of soaking in most cases, probably due to the solubility of iodine in water. The water used in soaking the sea mustard was not included in the sample for iodine analysis of the 'soaked' samples because it is neither used nor consumed in the Korean diet.

The iodine content in sea mustard calculated from the values in the 'boiled' samples and converted to a dry weight basis decreased further to 113.65 ± 22.80 mg/kg, ranging from 79.49 ± 5.76 mg/kg (Ulsan) to 154.52 ± 23.95 mg/kg (Gwangju) (**Fig. 1**). Hence, the iodine content in sea mustard seems to change with heat (boiling).

Iodine content in dried kelp samples according to the preparation/cooking method

The mean (± SD) iodine content in kelp calculated from the values in the 'as is' samples was 1,484.08 ± 257.12 mg/kg, and the mean for the samples from each of the nine cities ranged from 1,272.11 ± 58.95 mg/kg (Suwon) to 1,870.42 ± 236.56 mg/kg (Seoul) (**Fig. 2**).

The mean iodine content in kelp calculated from the 'soaked' samples and converted to a dry weight basis was much lower: 234.48 ± 69.72 mg/kg, ranging from 166.26 ± 29.66 mg/kg (Incheon) to 314.36 ± 85.79 mg/kg (Daegu). The water used in soaking the kelp was not included in the sample for iodine analysis of the 'soaked' kelp samples because it is neither used nor consumed in the Korean diet. The iodine content in kelp decreased by 75% to 88% after 60 min of soaking in water at room temperature (**Fig. 2**).

In contrast, the iodine content in kelp calculated from the values in the 'boiled' samples and converted to a dry weight basis did not decrease but rather increased in some cases (**Fig. 2**). The mean content was 1,533.04 ± 629.32 mg/kg, ranging from 687.54 ± 125.08 mg/kg (Daejeon) to 2,740.21 ± 308.37 mg/kg (Ulsan). The difficulty in obtaining a rather uniform suspension of homogenates due to the unique texture/matrix of kelp and its very high iodine content appears to be the source of such variation.

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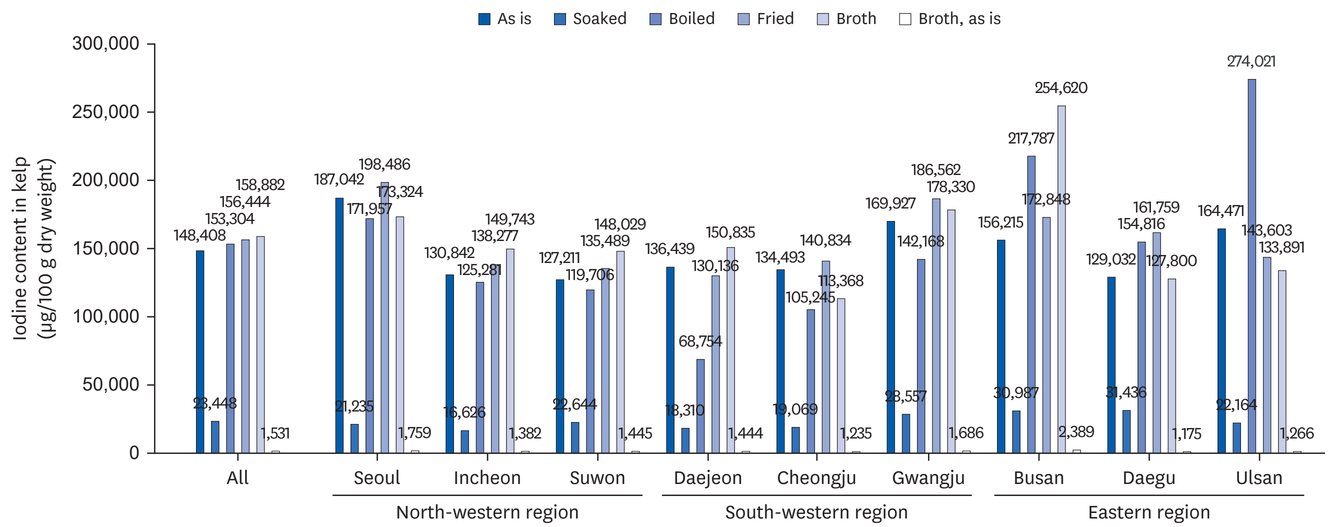

Fig. 2. Iodine content in kelp (μg/100 g dry weight) according to the city and preparation method.
The iodine content in the prepared samples was converted to the corresponding value in dried kelp.
As is, dried kelp; soaked, dried kelp soaked in water for 60 min and drained; boiled, dried kelp boiled for 15 min; Broth, kelp broth; Broth, as is, Iodine content in kelp broth (liquid) prepared, cooled and boiled again for 15 min as explained in the **Supplementary Table 1**.

Although the increase was not statistically significant, similar results were observed in the kelp samples prepared/cooked using different method. The iodine content in kelp calculated from the values in 'fried' samples and converted to a dry weight basis was 1,564.44 ± 278.69 mg/kg, ranging from 1,301.36 ± 126.44 mg/kg (Daejeon) to 1,984.86 ± 130.03 mg/kg (Seoul). A previous study [9] reported that heating may expedite the release of iodine in the complex matrix of kelp to a free form that is easily detected.

The mean iodine concentration in kelp broth was 15.31 ± 4.38 mg/kg, ranging from 11.75 ± 1.43 mg/kg (Daegu) to 23.89 ± 1.77 mg/kg (Busan). Considering the 125-fold dilution at the first step and some incidental concentration due to boiling of the broth-making process, mean iodine content in kelp calculated from the values in 'kelp broth' samples and converted to a dry weight basis was approximately 100-fold higher: 1,588.82 ± 480.86 mg/kg, ranging from 1,133.68 ± 171.71 mg/kg (Cheongju) to 2,546.20 ± 188.70 mg/kg (Busan) (**Fig. 2**).

Estimated dietary iodine intake of Koreans due to brown seaweed consumption

The iodine intake of the Korean population from brown seaweed consumption was estimated based on seaweed intake data from the aforementioned 40,166 subjects of KNHANES 2016–2021 with individual sampling weight given in the raw data set and the corresponding iodine contents of seaweed according to the type and method of preparation/cooking.

Table 2 lists the brown seaweed intake per person per day for mean and distribution according to the type of seaweed consumed. Although the intake data from KNHANES was obtained from the one day 24-h recalls, the data for 6 yrs merged into one dataset showed that the proportion of brown seaweed consumers in the distribution would be very close to the real proportion based on the usual diet of Koreans. Sea mustard was consumed by more than 10% of the total population on the survey date. Compared to this, kelp was consumed by less than 5% of the total population. On the other hand, kelp broth was consumed by more than a quarter of children and adults.

Table 2. Mean and distribution of brown seaweed intake of the Korean population according to the age group (n = 40,166)

Seaweed	Age group	%	Brown seaweed intake (g/day)									
			Mean ± SE	5th	10th	25th	50th	75th	90th	95th	97.5th	99th
Dried sea mustard	All (≥ 1)	100.0	0.77 ± 0.02	0.00	0.00	0.00	0.00	0.00	2.57	5.61	8.46	13.11
	1–2	1.5	0.56 ± 0.06	0.00	0.00	0.00	0.00	0.00	1.85	3.16	5.75	7.55
	3–5	2.6	0.62 ± 0.06	0.00	0.00	0.00	0.00	0.00	2.27	3.75	5.03	6.92
	6–11	5.4	0.55 ± 0.04	0.00	0.00	0.00	0.00	0.00	2.02	4.13	6.08	8.02
	12–18	7.0	0.52 ± 0.05	0.00	0.00	0.00	0.00	0.00	0.81	4.44	6.28	9.25
	19–64	68.8	0.76 ± 0.02	0.00	0.00	0.00	0.00	0.00	2.65	5.71	8.50	12.58
	≥ 65	14.8	1.03 ± 0.05	0.00	0.00	0.00	0.00	0.00	3.33	7.38	11.71	17.53
Dried kelp	All (≥ 1)	100.0	0.08 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	2.01
	1–2	1.5	0.03 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.53	0.72
	3–5	2.6	0.07 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.80	1.06
	6–11	5.4	0.07 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.78	1.22
	12–18	7.0	0.06 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.79	1.55
	19–64	68.8	0.08 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	2.14
	≥ 65	14.8	0.08 ± 0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	2.69
Kelp broth	All (≥ 1)	100.0	22.70 ± 0.65	0.00	0.00	0.00	0.00	0.00	48.75	130.00	250.00	417.05
	1–2	1.5	17.74 ± 2.00	0.00	0.00	0.00	0.00	11.21	44.18	99.54	150.00	200.05
	3–5	2.6	18.95 ± 1.72	0.00	0.00	0.00	0.00	17.57	50.93	88.36	146.47	292.61
	6–11	5.4	18.98 ± 1.27	0.00	0.00	0.00	0.00	14.91	55.94	88.85	159.99	265.15
	12–18	7.0	19.84 ± 1.94	0.00	0.00	0.00	0.00	0.00	45.04	99.80	217.64	350.08
	19–64	68.8	22.62 ± 0.75	0.00	0.00	0.00	0.00	0.69	47.59	132.35	250.00	416.66
	≥ 65	14.8	26.89 ± 1.41	0.00	0.00	0.00	0.00	0.00	49.31	200.00	350.00	533.28

The iodine contents of the seaweed samples prepared/cooked using representative methods were applied to the seaweed intake at the individual level, as listed in **Table 3**. The mean (± SE) daily iodine intake from sea mustard was 96.01 ± 2.36 μg/day, and the 95th percentile intake was seven times higher, 681.76 μg/day, in the Korean population.

Although the iodine content in kelp was approximately seven times higher than that in sea mustard, the mean daily intake of iodine due to the consumption of kelp (except broth) was not much higher than that with sea mustard, 115.58 ± 7.71 μg/day. Because only 4.4% of the subjects reported kelp consumption other than broth, the 95th percentile intake was 0 μg/day, and the 97.5th and 99th percentile intakes (894.12 and 3,051.43 μg/day) are shown.

Kelp broth was consumed more broadly by 24.8% of the Korean population in many different soups and stews. The mean daily intake of iodine from kelp broth was 347.57 ± 10.03 μg/day, with the 95th percentile intake of 1,990.42 μg/day (**Table 3**). Altogether, the mean daily iodine intake from brown seaweed in the Korean population was 559.16 ± 13.15 μg/day, and the 95th percentile intake was higher than five times the mean, 3,062.07 μg/day (**Table 3**). This mean intake was well over the recommended nutrient intake (RNI) of iodine (150 μg/day for adults) but much lower than the UL set in DRIs for Koreans [7].

The total iodine intake of Koreans from brown seaweed was subdivided into six age groups and listed in **Table 4** for the mean and 95th percentile, along with the proportion of the

Table 3. Estimated iodine intake from brown seaweed in the Korean population (n = 40,166)

Source	Iodine intake (μg/person/day)									
	Mean ± SE	5th	10th	25th	50th	75th	90th	95th	97.5th	99th
Sea mustard	96.01 ± 2.36	0.00	0.00	0.00	0.00	0.00	315.42	681.76	1,063.57	1,612.36
Kelp	115.58 ± 7.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	894.12	3,051.43
Kelp broth	347.57 ± 10.03	0.00	0.00	0.00	0.00	0.00	746.45	1,990.42	3,827.81	6,385.50
Altogether	559.16 ± 13.15	0.00	0.00	0.00	0.00	403.87	1,400.28	3,062.07	4,610.01	7,973.81

Table 4. Mean and the 95th percentile iodine intake (μg/person/day) of Koreans according to the source and age group (n = 40,166)

Age group (yrs)	%	Sea mustard		Kelp		Kelp broth		UL (μg/person/day)
		Mean	95th	Mean	95th	Mean	95th	
1–2	1.5	64.70	382.77[1)]	53.03	429.11[1)]	271.58	1,524.07[1)]	300 (1–5 yrs)
3–5	2.6	71.44	430.00[1)]	109.63	889.76[1)]	290.20	1,352.95[1)]	
6–11	5.4	63.64	474.20	100.24	503.05[1)]	290.66	1,360.37[1)]	500 (6–11 yrs)
12–18	7.0	59.27	498.51	89.64	45.23	303.85	1,528.01	1,900 (12–14 yrs) 2,200 (15–18 yrs)
19–64	68.8	93.87	687.06	119.13	0.00	346.40	2,026.48	2,400 (≥ 19 yrs)
≥ 65	14.8	125.76	861.02	124.15	0.00	411.70	3,062.21[1)]	

UL, tolerable upper intake level.
[1)]Iodine intake higher than the corresponding UL.

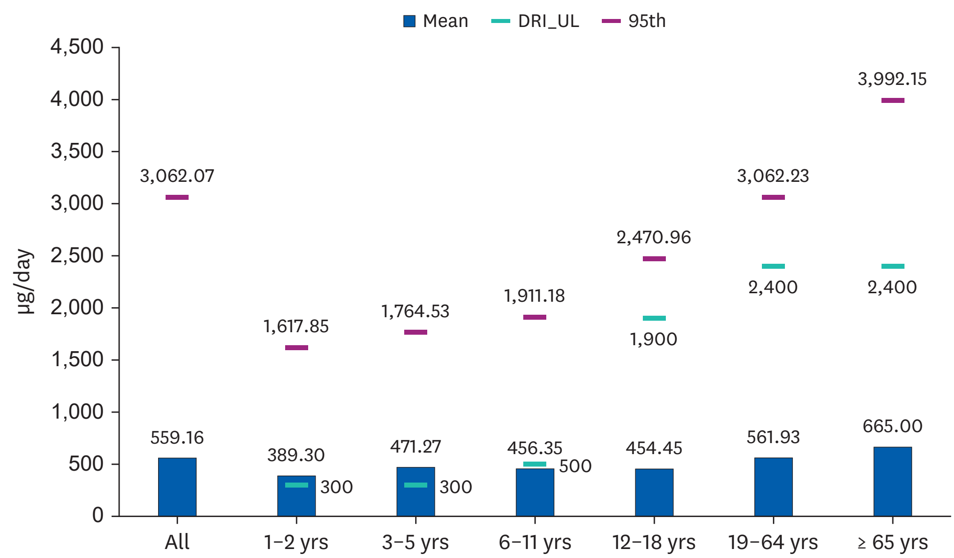

Fig. 3. Mean and 95th percentile intake of iodine according to the age group in the Korean population with the corresponding ULs. All analyses accounted for the complex sampling design effect and appropriate sampling weights. DRI, Dietary Reference Intake; UL, tolerable upper intake level.

population with an iodine intake exceeding the corresponding ULs for easier comparison. Based on the single-day food intake data, 8.8% of the Korean population showed iodine intake higher than the UL, and the proportion in children ranged from 25.6% to 38.8%, much higher than that in adults, as can be seen in **Fig. 3** with the corresponding ULs. **Table 4** lists the mean and the 95th percentile iodine intake from three sources of brown seaweed and age group.

Estimated dietary iodine intake in brown seaweed 'consumers'

In addition to the estimation of iodine intake for the whole Korean population, the intake of those who consumed brown seaweed on the survey date was also estimated in the same manner. **Table 5** lists proportion of brown seaweed consumers among all subjects in the KNHANES 2016 through 2021 according to the age group and type of brown seaweed.

Any consumer could consume more than one type of brown seaweed in one day. **Table 6** lists the iodine intake for each seaweed separately in addition to the total iodine intake of consumers who consumed one or more types of brown seaweed on the survey date. The mean iodine intake from brown seaweed was 1,495.44 ± 30.12 μg/person/day, and the 95th percentile intake was 5,741.71 μg/person/day, approximately 90% higher than the corresponding value for the Korean population (bottom row of **Table 6**).

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Table 5. Brown seaweed consumers and proportion according to the source and age group (n = 40,166)

Age group (yrs)	%	Consumers			
		One or more brown seaweed	Sea mustard	Kelp	Kelp broth
		%	%	%	%
1–2	1.5	52.1	22.2	7.4	31.9
3–5	2.6	50.0	22.9	9.0	31.4
6–11	5.4	45.5	15.7	6.9	31.7
12–18	7.0	34.3	11.7	5.3	24.2
19–64	68.8	37.2	14.4	3.9	25.2
≥ 65	14.8	33.3	14.9	4.2	18.5
Total	100.0	37.4	14.7	4.4	24.8

Table 6. Mean and distribution of the iodine intake in brown seaweed consumers

Seaweed consumed	No. of consumers	Iodine intake (μg/person/day)						
		Mean ± SE	5th	10th	25th	50th	75th	90th	95th
Sea mustard	6,050	653.16 ± 11.12	10.55	88.93	247.36	501.42	855.18	1,367.32	1,878.52
Kelp	1,854	2,655.04 ± 147.87	6.87	51.57	415.99	1,120.64	2,817.25	6,284.72	10,238.97
Kelp broth	9,764	1,403.71 ± 34.32	38.39	76.86	217.12	548.11	1,501.57	3,827.81	5,741.82
One or more of the above	15,091	1,495.44 ± 30.12	53.64	115.43	303.55	670.03	1,519.96	3,827.77	5,741.71

Table 7. Mean and distribution of the iodine intake in brown seaweed consumers according to the age group (n = 15,091)

Age group (yrs)	%	Iodine intake (μg/person/day)							
		Mean ± SE	5th	10th	25th	50th	75th	90th	95th
1–2	2.0	746.55 ± 55.48	34.03	53.88	197.1	449.51[1)]	826.89[1)]	1,599.04[1)]	2,420.71[1)]
3–5	3.4	942.69 ± 60.96	98.22	164.84	332.25[1)]	585.90[1)]	1,071.80[1)]	1,764.77[1)]	2,943.85[1)]
6–11	6.5	1,002.61 ± 60.91	71.39	135.27	299.55	603.83[1)]	1,085.75[1)]	1,968.57[1)]	3,160.93[1)]
12–18	6.4	1,323.43 ± 85.49	61.38	140.95	319.01	678.84	1,374.15	3,302.40[1)]	4,805.83[1)]
19–64	68.4	1,512.30 ± 37.28	49.58	115.42	298.93	659.53	1,515.36	3,827.77[1)]	5,755.88[1)]
≥ 65	13.2	1,994.68 ± 65.57	76.86	141.16	365.82	864.49	2,295.83	5,358.92[1)]	7,655.40[1)]

[1)]Iodine intake higher than the corresponding tolerable upper intake level.

Brown seaweed consumers were further divided into six age groups. **Table 7** lists the mean and 95th percentile iodine intake for each group. High proportions of consumers with intake exceeding the ULs were noted among young children. More than half of the young consumers under 12 yrs of age showed an iodine intake exceeding ULs on the survey date, while such high intake values appeared from the 90th percentile in adolescents and adults, including the elderly.

In addition, the iodine content in one portion of soups and other prepared dishes using brown seaweed as an ingredient was derived using the same intake data of KNHANES. The mode and median portion size for kelp wrap (soaked kelp), consumed by 0.5% of the subjects, corresponded to 0.69 and 2.16 g of dried kelp, resulting in an iodine intake of 162 and 506 μg, respectively. The mode and median portion size for fried kelp (called 'Twee-gag' in Korean and consumed by 0.1% of the subjects) corresponded to 3.3 g of dried kelp, resulting in an iodine intake of 5,163 μg. On the other hand, the mode and median portion size for sea mustard soup (boiled sea mustard), one of the most popular soups in the Korean diet and consumed by 5.0% of the subjects on the survey date, was 250 mL, corresponding to 9.36 g of dried sea mustard and an iodine intake of 1,064 μg. One bowl of sea mustard soup per week, not per day, would meet the RNI of iodine for the Korean adult population.

DISCUSSION

As shown in the figures, the iodine content in brown seaweed varied considerably among the samples prepared/cooked in different ways, in addition to the variability due to collection sites. Besides, the result of kelp broth may require more attention. The iodine content in kelp broth converted to a dry weight basis was comparable to the content in the dried 'as is' kelp sample, suggesting the almost perfect migration of iodine from kelp to the broth. Ishizuki *et al.* [15] reported a similar finding in Japan; the migration rate of iodine from kelp to water was 99% after boiling for 15 min.

A closer-to-real estimate of the iodine intake from brown seaweed in the Korean population could be made by incorporating these variabilities of content into the individual brown seaweed intake data, 559.16 ± 13.15 μg/day. Although a much higher iodine intake of 1–3 mg/day has been reported in the Japanese population [16,17], their estimation was based on either the combination of information from diet records, food surveys, urine iodine analysis (both spot and 24-h samples) and seaweed iodine content or the food balance sheet and values in literature. Such an approach may result in an overestimation of the iodine intake compared with the present method using the national food intake data and the iodine content of the relevant seaweed obtained from the analysis of samples prepared to a 'ready-to-consume' state.

The contribution of kelp broth to iodine intake due to brown seaweed was rather large (62.2%) in Koreans, which is one of the interesting points of these findings. Although Koreans consume little of the solid type of kelp in their usual diet compared to the Japanese, kelp broth as a base is used in many different soups and stews. This was reflected in the source of iodine intake in **Table 5**, verifying the highest contribution of kelp broth.

Although the mean iodine intake of the Korean population, even from brown seaweed only, appears to be well over the ULs set in countries, such as Germany [18], people's usual diet differs considerably between countries, which must be considered when interpreting the results. Having various seafoods, including seaweed, as a common ingredient in their usual diet for centuries, Koreans have adapted to a higher level of iodine intake and may metabolize iodine from food sources differently from those living on prolonged iodine-deficient diet. This could explain why personal nutriture or nutrient load must be reflected in the nutritional risk assessment, as Food and Nutrition Board stated [19]. Ishizuki *et al.* [15] reported the disappearance of thyrotoxic signs, which resulted from dietary iodine intake of 28–140 mg/day for a certain period within a month after ceasing kelp intake. This also supports the possibility of different metabolism and iodine requirements [8] in different populations with different iodine nutritional status.

The present estimation was based on the dietary intake data from a 24-h recall. Although the merged intake data from 6 yrs was used to decrease the bias due to inter- and intra-individual variability, it still could result in a broader distribution than that of the usual intake. Only a quarter of the subjects consumed kelp broth, the most popular form of brown seaweed intake, on the survey date, and the proportion of subjects who consumed any form of brown seaweed was 37.6%, suggesting that Koreans do not consume brown seaweed daily. Therefore, the real distribution of the usual iodine intake from brown seaweed in Koreans might be much tighter, resulting in a lower 95th percentile value than what was presented in this study and probably under the ULs set for the daily intake for life. Nevertheless, the total iodine intake from all food sources in the Korean diet might be at least 50% higher than the present result because brown seaweed contributed to 63.9% of the total iodine intake in Koreans [9].

The UIC was assessed in samples obtained from 8,318 subjects 10 yrs and older in the 6th KNHANES (2013–2015), and the median (interquartile range) was reported to be 293.9 μg/L (156.5–683.6 μg/L) [20], which was lower than the value reported for school-age children (6–19 yrs) in Korea in the Global Scorecard of Iodine Nutrition in 2021 [21]. Although the median values for urinary iodine above 200 μg/L in adults are not recommended in populations characterized by longstanding iodine deficiency with rapid increases in iodine intake because of the risk of iodine-induced hyperthyroidism [22], Koreans rarely have iodine deficiency and stayed 'apparently healthy' for centuries with habitual brown seaweed consumption that the cutoff of 200 μg/L in adults may not be applicable.

In summary, based on the 6 yrs of national dietary intake data derived from a 24-h recall, the mean iodine intake from brown seaweed in the Korean population was estimated to be 559.16 ± 13.15 μg/day, and the median was 0 because only 37.6% of the Korean population consumed brown seaweed on the survey date. In comparison, the iodine intake of brown seaweed consumers was much higher, 1,495.44 ± 30.12 μg/person/day and 670.03 μg/day for the mean and median, respectively. The proportion of the Korean population with an iodine intake from brown seaweed exceeding the UL was 8.8% for one year and older while that of the brown seaweed consumer population was much higher, more than 50% in children with rather low ULs.

Although the estimated average requirement and the RNI for iodine for Koreans [5] are similar to those set for Americans [23] through all age groups, the ULs are quite different. While the ULs of Korean adolescents and adults (1,900–2,200 μg/day and 2,400 μg/day) are approximately double of those set for Americans (900 and 1,100 μg/day), those for children are similar. Hence, we have a rather abrupt increase (from 500 to 1,900 μg/day) in ULs between 9–11 yrs old and younger adolescents, 12–14 yrs old. This might have been due to a lack of appropriate data and/or literature on the iodine intake in children. With such a leap in UL values, the proportion of children with iodine intakes higher than UL could have been overestimated.

While the Institute of Medicine (US) Panel on Micronutrients [23] suggested a formula to estimate the iodine intake based on the UIC, iodine intake estimated with this formula in Korean children [24], a median of 535 μg/day, appeared to be different from that of a previous study [9] and the present estimates based on dietary intake data. Considering that UIC reflects the recent iodine nutrition (days) [23], further study evaluating the iodine intake status of Koreans based on the usual intake is warranted. Since the additional 24-hour recall data was collected from some of the subjects in the KNHANES 2019, estimating the usual iodine intake based on the data from 2 non-consecutive days would be feasible as soon as the data becomes publicly available. This study adds additional data to the limited literature on the iodine nutriture of Koreans.

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SUPPLEMENTARY MATERIAL

Supplementary Table 1

Preparation/cooking of brown seaweed samples for analysis

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