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Assessment of dietary iodine intake and its sources among Koreans: a cross-sectional analysis from the Korea National Health and Nutrition Examination Survey 2019–2021

Jee-Seon Shim [1,2], **Ki Nam Kim** [3], **Jung-Sug Lee** [4], **and Hyun Sook Lee** [5§]

[1]Department of Preventive Medicine, Yonsei University College of Medicine, Seoul 03722, Korea
[2]Institute for Innovation in Digital Healthcare, Yonsei University Health System, Seoul 03722, Korea
[3]Department of Food and Nutrition, Daejeon University, Daejeon 34520, Korea
[4]Department of Food and Nutrition, Kookmin University, Seoul 02707, Korea
[5]Department of Food and Nutrition, Dongseo University, Busan 47011, Korea

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§Corresponding Author:
Hyun Sook Lee
Department of Food and Nutrition, Dongseo University, 47 Jurye-ro, Sasang-gu, Busan 47011, Korea.
Tel. +82-51-320-1794
Fax. +82-51-320-1781
Email. hyunlee@gdsu.dongseo.ac.kr

ORCID iDs
Jee-Seon Shim
https://orcid.org/0000-0002-8671-3153
Ki Nam Kim
https://orcid.org/0000-0002-9485-567X
Jung-Sug Lee
https://orcid.org/0000-0001-8738-6409
Hyun Sook Lee
https://orcid.org/0000-0002-8642-1978

ABSTRACT

BACKGROUND/OBJECTIVES: Iodine is an essential mineral that is critical for humans, as inadequate and excessive intake can lead to adverse health outcomes. Data on dietary iodine intake and adequacy among Koreans remain limited. This study aimed to estimate the dietary iodine intake of Koreans, assess the adequacy of intake, and examine the primary dietary sources of iodine in the Korean population.
SUBJECTS/METHODS: This study analyzed data from 18,895 participants aged ≥ 1 yr obtained from the Korea National Health and Nutrition Examination Survey (KNHANES) 2019–2021. Dietary iodine intake was calculated using a newly constructed iodine database applied to KNHANES data. Intake levels were compared against the sex- and age-specific reference values outlined in the Korean Dietary Reference Intakes 2020. Insufficient intake was below the estimated average requirement (EAR), while excessive intake was above the tolerable upper intake level (UL).
RESULTS: The median iodine intake of Koreans aged ≥ 1 yr was 114 μg/d, corresponding to 123% of the EAR. Approximately 4 in 10 Koreans did not meet the EAR, one exceeded the UL, and only 5 had adequate iodine intake. Excessive intake was most prevalent among children under 12 yrs of age. Two-thirds of iodine intake came from plant-based foods, with seaweed, eggs, fish, milk, and grains identified as the major dietary contributors.
CONCLUSION: Koreans' median dietary iodine intake appears adequate; however, a significant proportion exhibit insufficient or excessive intake. Further research is needed to estimate usual iodine intake and develop strategies for addressing problematic iodine intake.

Keywords: Iodine; diet; nutrition surveys; South Korea; food analysis; seaweed

INTRODUCTION

Iodine is an essential component of thyroid hormones—tri-iodothyronine (T3) and thyroxine (T4)—which are vital for the growth, development, and regulation of energy metabolism in

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Conflict of Interest
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the human body [1]. Dietary iodine has various forms, including sodium and potassium salts, inorganic iodine, iodide, and iodate [2]. After ingestion, iodine is metabolized to iodide in the gastrointestinal tract, primarily absorbed in the stomach and duodenum [3]. Once absorbed, iodine accumulates in the thyroid, salivary glands, gastric mucosa, and mammary glands. The remaining iodine, not taken up by the body, is excreted through urine [2,3].

Insufficient iodine intake can result in thyroid dysfunction and other adverse health effects [3-6]. Maternal iodine deficiency has significant consequences, such as fetal hypothyroidism and irreversible neurological and cognitive deficits due to impaired fetal brain development. Postnatal iodine deficiency is also associated with cognitive dysfunction [4]. Severe iodine deficiency in adulthood may lead to hypothyroidism, goiter, mental disabilities, and reduced fertility [6]. In contrast, excessive iodine intake can alter thyroid function by increasing thyroxine levels and suppressing thyroid-stimulating hormone concentrations [5]. Although the impact biochemical effects of excessive iodine intake remain unclear, there is growing concern about its potential health risks.

Iodine occurs naturally in soil and oceans. Foods of marine origin, such as seaweed and fish, are rich in iodine because they accumulate iodine from seawater. Conversely, plants and animals cultivated in iodine-deficient inland soils have relatively low iodine content [3]. Consequently, people living in inland regions are more likely to have lower iodine intake than coastal residents. A 2004 World Health Organization (WHO) report shows that 35.2% of the global population has insufficient iodine intake. Regional disparities were notable, with over half of European and Eastern Mediterranean populations affected [7]. Many regions have implemented iodine fortification programs to combat iodine deficiency, resulting in substantial progress.

Unlike iodine-deficient regions, Korea is surrounded by sea on 3 sides. Koreans consume a variety of iodine-rich seaweeds and fish [8], leading to an estimated high iodine intake. To address nutritional concerns, the Korean government conducted the Korea National Health and Nutrition Examination Survey (KNHANES) to assess its population's dietary and nutritional status. However, iodine intake data have not been publicized due to the lack of a comprehensive food iodine database. Recently, the Korea Disease Control and Prevention Agency (KDCA), which oversees KNHANES, expanded its nutrient database to include dietary micronutrient intakes [9-11]. As a part of this effort, we developed a database detailing the iodine content of foods consumed in KNHANES [12]. This study aimed to estimate the dietary iodine intake in Koreans using the newly constructed iodine database and investigate the dietary sources of iodine in Koreans.

SUBJECTS AND METHODS

Data source and study population

This study used data from the KNHANES VIII (2019–2021), a nationwide cross-sectional survey that provides information about the health and nutrition status of Koreans aged ≥ 1 yr. The KNHANES comprises health interviews, health examinations, and nutritional surveys. The survey participants were selected through a multi-stage clustered probability design to ensure representative samples of the non-institutionalized Korean population. Each participant was assigned a sample weight to reflect the population distribution. This study used raw data from the KDCA (https://knhanes.cda.go.kr, accessed on 29 December 2022).

Additional details are provided elsewhere [13,14]. The study protocol was approved by the Institutional Review Board (IRB) of the KDCA (IRB No. 2018-01-03-C-A, 2018-01-03-2C-A, and 2018-01-03-5C-A). Written informed consent was obtained from all participants and confirmed by the IRB.

Among 22,559 participants in the KNHANES VIII (2019–2021), individuals who completed the 24-h recall of the nutritional survey were included in this study (n = 18,895).

Dietary assessment

The dietary assessment in the KNHANES has been described previously [11,13]. Briefly, participants' diets were assessed using a one-day, 24-h dietary recall. Trained dietitians collected detailed dietary information, including a list of foods and beverages consumed the previous day, preparation methods, and eating locations. The quantities consumed were measured using various aids (e.g., measuring cups, spoons, rulers, and photographs) and converted into weights (g) using a food volume and weight database.

Nutrient intake was calculated using the Korean Food Composition Table developed by the National Institute of Agricultural Sciences [15]; however, dietary iodine intake was not included, as the table lacks data on iodine content in foods. Further details on the KNHANES 24-h recall are available elsewhere [11,13].

Establishment of iodine content database and estimation of dietary iodine intake

We established a database of iodine content for foods reported as consumed by KNHANES participants from 2016–2021, along with additional foods requested by the KDCA. Further details of the newly established iodine content database can be found in the report [12]. Briefly, data on iodine content were gathered from domestic and international food composition tables and nutritional fact labels of processed foods published through early 2023 [15-27]. Before database construction, we defined principles for data source selection, prioritization in cases of multiple analytical values, and application of substitute values. These considerations were based on guidelines for producing, managing, and using food composition data [28].

The established iodine database covered 99.55% (n = 4,396) of the foods reported in the KNHANES (n = 4,416). The database consisted of 1,174 analytical values, 643 calculated values, and 2,579 substituted values. Most of the data was sourced domestically (n = 3,795), with the remainder from international sources (n = 601). Dietary iodine intake was calculated using the constructed iodine database to raw data from the KNHANES 24-h dietary recall.

Statistical analysis

Dietary iodine intake is presented as percentiles (2.5th, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97.5th) along with the mean and standard error. Dietary iodine intake was analyzed as absolute intake (μg/day) and relative intake, expressed as a percentage of the estimated average requirement (EAR) by sex and age, according to the Korean Dietary Reference Intakes 2020 [2]. The relative intake was assessed for pregnant and lactating women, considering their increased needs during pregnancy and breastfeeding. The prevalence of insufficient intake (below the EAR) and excessive intake (above the tolerable upper intake level, UL) was determined as a proportion of the population meeting these thresholds. All analyses were stratified by total population, sex, and age groups.

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To identify the major contributors to dietary iodine intake, we calculated the intake from each food group and its percentage contribution to total iodine intake. This analysis was also performed at the food level using the tertiary food codes in the KNHANES raw dataset. The top 20 food items contributing to iodine intake were presented, stratified by sex and age group.

All statistical analyses were performed using SAS software (version 9.4; SAS Institute, Cary, NC, USA). The sampling weights and survey design of the KNHANES were accounted for in all analyses. Statistical significance was set at a *P*-value of < 0.05.

RESULTS

Absolute and relative intake of dietary iodine

Table 1 shows the distribution and mean absolute dietary iodine intake among Koreans, stratified by total population, sex and age group. For the total population aged ≥ 1 yr, iodine

Table 1. Absolute dietary iodine intake (ug/day) of Koreans, KNHANES VIII (2019–2021)

Variables	Number	Percentile									Mean ± SE
		2.5	5	10	25	50	75	90	95	97.5	
All (≥ 1 yr)	18,895	8	12	19	44	114	550	1,710	4,012	6,434	785 ± 26
Adults (≥ 19 yrs)	15,549	7	12	19	43	111	532	1,771	4,328	6,603	812 ± 28
Age group (yrs)											
1–2	290	8	15	30	62	151	762	1,395	2,198	3,330	600 ± 65
3–5	568	13	19	30	61	187	848	1,886	2,434	4,901	716 ± 69
6–11	1,319	10	16	29	60	149	739	1,559	2,459	3,922	647 ± 47
12–18	1,169	8	13	20	44	104	442	1,420	3,024	5,489	610 ± 58
19–29	1,877	8	12	17	34	82	275	1,031	1,779	4,297	468 ± 36
30–49	4,690	9	13	21	47	117	543	1,571	3,879	6,081	765 ± 47
50–64	4,390	8	13	21	54	139	707	2,479	5,299	8,519	1,018 ± 54
≥ 65	4,592	5	8	14	31	93	496	2,301	5,360	8,512	906 ± 47
P-value[1)]											< 0.001
Males (≥ 1 yr)	8,453	9	14	21	49	128	645	1,842	4,287	6,579	850 ± 36
Adults (≥ 19 yrs)	6,719	9	14	21	47	127	638	1,936	4,484	6,812	883 ± 40
Age group (yrs)											
1–2	139	8	12	28	62	153	794	1,217	1,738	1,821	470 ± 54
3–5	299	14	20	31	60	164	746	1,630	2,340	4,662	677 ± 93
6–11	679	11	19	29	55	143	835	1,812	2,513	3,570	661 ± 57
12–18	617	7	14	23	52	118	511	1,674	3,617	6,203	730 ± 93
19–29	894	8	13	18	37	84	350	1,234	2,389	5,336	547 ± 58
30–49	2,026	10	15	22	50	140	642	1,590	3,629	5,428	511 ± 77
50–64	1,845	10	14	23	59	161	822	2,691	5,379	9,786	1,138 ± 77
≥ 65	1,954	8	12	18	40	107	581	2,621	5,924	8,530	974 ± 62
P-value											< 0.001
Females (≥ 1 yr)	10,442	6	11	17	40	100	451	1,605	3,729	6,313	720 ± 26
Adults (≥ 19 yrs)	8,830	6	10	17	39	97	431	1,634	4,144	6,436	743 ± 28
Age group (yrs)											
1–2	151	4	16	30	62	146	689	1,621	3,364	5,224	737 ± 129
3–5	269	11	18	30	61	219	945	2,012	2,434	4,735	760 ± 103
6–11	640	9	15	28	63	152	661	1,374	2,337	4,274	612 ± 62
12–18	552	8	12	17	37	89	278	967	2,252	4,037	471 ± 56
19–29	983	7	11	16	33	77	224	821	1,275	2,857	382 ± 40
30–49	2,664	9	12	19	44	99	423	1,479	4,219	6,315	715 ± 47
50–64	2,545	6	12	20	50	123	616	2,140	4,882	6,901	899 ± 55
≥ 65	2,638	4	6	12	26	79	440	2,145	4,921	8,417	854 ± 55
P-value											< 0.001

KNHANES, Korea National Health and Nutrition Examination Survey.
[1)]*P*-value for differences between age groups.
P-value for the difference between males and females aged ≥ 1 yr and ≥ 19 yrs was 0.0004 and 0.0007, respectively.

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intake ranged from 8 μg/day (2.5th percentile) to 6,434 μg/day (97.5th percentile), with a median intake of 114 μg/day and a mean intake of 785 μg/day. Dietary iodine intake was heavily skewed to the right across all groups. Overall, males had higher dietary iodine intake than females, while young adults aged 19–29 yrs and older people aged ≥ 65 yrs consumed less iodine compared to other age groups.

Table 2 shows the distribution and mean relative iodine intake as a percentage of the sex- and age-specific EAR for Koreans. Among the population aged ≥ 1 yr, the median iodine intake relative to the EAR was 123%. Similar to the distribution of absolute iodine intake, the relative intake distribution was also skewed heavily to the right across all groups, with males showing higher relative intake compared to females. The median relative intake for young adults was lower than the EAR, whereas the median intake for children under 12 yrs was 2 to 3 times higher than the EAR.

Table 2. Relative dietary iodine intake (% EAR) of Koreans, KNHANES VIII (2019–2021)

Variables	Percentile									EAR[1] (μg/d)	Mean ± SE
	2.5	5	10	25	50	75	90	95	97.5		
All (≥ 1 yr)	8	13	21	47	123	595	1,894	4,319	6,822		847 ± 27
Adults (≥ 19 yrs)	8	12	20	45	116	554	1,858	4,541	6,925		853 ± 29
Age group (yrs)											
1–2	15	27	55	113	275	1,385	2,537	3,996	6,055		1,091 ± 119
3–5	19	30	47	94	288	1,305	2,901	3,744	7,540		1,102 ± 106
6–11	13	21	36	76	186	946	1,989	3,107	5,215		810 ± 60
12–18	9	14	21	47	111	475	1,546	3,261	6,066		660 ± 64
19–29	8	13	18	36	86	290	1,081	1,853	4,390		490 ± 38
30–49	9	14	21	48	123	567	1,643	4,002	6,342		798 ± 50
50–64	9	14	22	57	146	745	2,609	5,578	8,968		1,072 ± 57
≥ 65	5	8	15	33	98	522	2,422	5,642	8,960		954 ± 49
P-value[2]											< 0.001
Males (≥ 1 yr)	10	15	23	53	139	700	2,062	4,555	6,947		917 ± 38
Adults (≥ 19 yrs)	10	14	22	50	134	672	2,038	4,720	7,171		930 ± 42
Age group (yrs)											
1–2	15	22	51	112	278	1,443	2,213	3,160	3,310	55	854 ± 99
3–5	21	30	48	92	252	1,148	2,508	3,601	7,172	65	1,041 ± 143
6–11	14	23	36	72	175	1,037	2,135	3,151	4,551	75/85	830 ± 72
12–18	8	14	24	56	127	547	1,803	3,897	6,720	90/95	791 ± 102
19–29	9	13	19	39	89	369	1,299	2,515	5,617	95	576 ± 61
30–49	11	16	23	53	147	676	1,674	3,820	5,714	95	854 ± 81
50–64	10	15	25	62	169	866	2,832	5,662	10,301	95	1,197 ± 81
≥ 65	8	12	19	42	112	612	2,758	6,236	8,979	95	1,025 ± 65
P-value											< 0.001
Females (≥ 1 yr)	7	11	18	43	108	486	1,746	3,977	6,728		777 ± 28
Adults (≥ 19 yrs)	6	10	18	40	101	449	1,708	4,243	6,770		776 ± 29
Age group (yrs)											
1–2	8	28	55	112	265	1,253	2,947	6,116	9,499	55	1,340 ± 234
3–5	16	28	45	94	337	1,454	3,095	3,745	7,285	65	1,170 ± 159
6–11	11	20	36	81	199	863	1,758	2,969	5,568	75/80	791 ± 80
12–18	9	13	19	40	95	305	1,044	2,459	4,467	90/95	509 ± 61
19–29	7	11	17	33	81	236	863	1,340	2,535	95	395 ± 42
30–49	8	12	20	45	102	439	1,535	4,397	6,625	95	738 ± 48
50–64	7	13	21	52	129	649	2,252	5,139	7,264	95	947 ± 58
≥ 65	4	7	12	28	84	463	2,258	5,180	8,860	95	900 ± 58
P-value											< 0.001

EAR, estimated average requirement; KNHANES, Korea National Health and Nutrition Examination Survey.
[1]Sex- and age-specific EAR suggested by the Korean Dietary Reference Intake 2020. For some age groups, EARs were set separately for each subgroup. For males in the age group of 6–11 yrs, the EARs for 6–8 yrs and 9–11 yrs were 75 and 85 μg, respectively. For the age group of 12–18 yrs, each EAR for 12–14 and 15–18 yrs is presented. In addition, the EAR for pregnant women was set by adding 65 μg/day to the EAR of the relevant age group, and 130 μg/day for breastfeeding women.
[2]*P*-value for differences between age groups.

Adequacy of dietary iodine intake

Among the total population aged ≥ 1 yr, 45.3% had an adequate dietary iodine intake, whereas 44.3% consumed less than the EAR, and 10.4% exceeded the UL (**Table 3**). This pattern of iodine intake varied slightly by sex and age group. By sex, almost half of the males (48.0%) had adequate iodine intake, whereas 40.9% had intakes below the EAR. In contrast, nearly half of the females (47.7%) had inadequate intake, while 42.6% had adequate intake. By age groups, 30–40% of children under 12 yrs exceeded the UL for iodine intake, but the other age groups had lower excess intakes, with almost half of young adults and older individuals having insufficient iodine intake.

Dietary sources of iodine intake

Table 4 shows iodine intake from each food group and its contribution to the total intake for the total population, stratified by sex and age group. For the overall population, approximately two-thirds of total iodine intake came from plant-based foods. The major food groups contributing to total iodine intake were seaweed (41.6%), vegetables (9.3%), and grains (6.5%) from plant sources, and eggs (13.0%), fish (11.2%), and milk (8.4%) from animal sources. These trends were consistent across sexes but differed slightly by age group.

Table 3. Adequacy of dietary iodine intake of Koreans, KNHANES VIII (2019–2021)

Variables	Prevalence (%)		
	Insufficient intake (< EAR)	Adequate intake (EAR–UL)	Excessive intake (> UL)
All (≥ 1 yr)	44.3	45.3	10.4
Adults (≥ 19 yrs)	45.8	46.2	8.0
Age group (yrs)			
1–2	23.1	36.9	40.0
3–5	26.1	30.3	43.6
6–11	31.5	36.7	31.8
12–18	46.6	46.6	6.8
19–29	54.1	41.9	4.0
30–49	44.0	48.8	7.2
50–64	40.0	49.8	10.2
≥ 65	50.6	39.8	9.6
Males (≥ 1 yr)	40.9	48.0	11.1
Adults (≥ 19 yrs)	42.0	49.5	8.5
Age group (yrs)			
1–2	23.2	36.3	40.5
3–5	25.6	31.6	42.8
6–11	33.4	33.0	33.6
12–18	42.2	49.8	8.0
19–29	52.0	42.9	5.1
30–49	39.2	53.6	7.2
50–64	37.0	51.7	11.3
≥ 65	46.3	43.1	10.6
Females (≥ 1 yr)	47.7	42.6	9.7
Adults (≥ 19 yrs)	49.5	43.1	7.4
Age group (yrs)			
1–2	22.9	37.6	39.5
3–5	26.6	28.8	44.6
6–11	29.6	40.4	30.0
12–18	51.7	42.8	5.5
19–29	56.3	40.8	2.9
30–49	49.2	43.6	7.2
50–64	42.9	48.0	9.1
≥ 65	53.8	37.3	8.9

EAR, estimated average requirement; UL, tolerable upper intake level; KNHANES, Korea National Health and Nutrition Examination Survey.

Table 4. Dietary iodine intake of Koreans from food groups and their contribution to total iodine intake, KNHANES VIII (2019–2021)

Food groups	Total mean ± SE (%)[1)]	Sex		Age (yrs)		
		Males mean ± SE (%)	Females mean ± SE (%)	1–18 mean ± SE (%)	19–64 mean ± SE (%)	≥ 65 mean ± SE (%)
Grains	5.0 ± 0.1 (6.5)	5.5 ± 0.2 (6.5)	4.5 ± 0.1 (6.5)	6.2 ± 0.3 (7.4)	5.3 ± 0.1 (6.8)	2.4 ± 0.1 (4.1)
Potatoes·starches	0.1 ± 0.0 (0.2)	0.2 ± 0.0 (0.2)	0.1 ± 0.0 (0.2)	0.2 ± 0.0 (0.4)	0.1 ± 0.0 (0.2)	0.0 ± 0.0 (0.1)
Sugars·sweet	0.3 ± 0.0 (0.4)	0.3 ± 0.0 (0.4)	0.3 ± 0.0 (0.4)	0.4 ± 0.0 (0.5)	0.3 ± 0.0 (0.4)	0.1 ± 0.0 (0.1)
Legumes	0.2 ± 0.0 (0.3)	0.2 ± 0.0 (0.3)	0.2 ± 0.0 (0.3)	0.1 ± 0.0 (0.2)	0.2 ± 0.0 (0.2)	0.2 ± 0.0 (0.5)
Nuts·seeds	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.1)	0.1 ± 0.0 (0.1)
Vegetables	6.1 ± 0.1 (9.3)	7.2 ± 0.1 (9.9)	5.0 ± 0.1 (8.8)	3.1 ± 0.1 (4.3)	6.5 ± 0.1 (9.5)	6.9 ± 0.1 (13.7)
Mushrooms	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.1)	0.0 ± 0.0 (0.0)
Fruits	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.4)	0.4 ± 0.1 (0.4)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)
Seaweed	717.8 ± 25.4 (41.6)	775.9 ± 35.9 (42.4)	659.5 ± 25.9 (40.9)	570.7 ± 34.5 (45.5)	720.9 ± 31.3 (41.2)	849.4 ± 46.4 (39.7)
Seasonings	4.8 ± 0.3 (4.0)	5.3 ± 0.4 (4.0)	4.3 ± 0.5 (4.0)	4.0 ± 0.7 (2.1)	4.9 ± 0.4 (3.6)	5.1 ± 0.2 (7.4)
Oils·fats (plant)	0.1 ± 0.0 (0.1)	0.1 ± 0.0 (0.2)	0.1 ± 0.0 (0.1)	0.1 ± 0.0 (0.2)	0.1 ± 0.0 (0.2)	0.0 ± 0.0 (0.1)
Others (plant)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)
Meats	2.7 ± 0.2 (2.5)	3.3 ± 0.3 (2.8)	2.0 ± 0.1 (2.2)	4.7 ± 0.5 (3.1)	2.6 ± 0.2 (2.6)	0.7 ± 0.1 (1.3)
Eggs	18.2 ± 0.3 (13.0)	19.5 ± 0.4 (12.4)	16.9 ± 0.3 (13.6)	19.1 ± 0.6 (13.6)	18.9 ± 0.4 (13.3)	14.4 ± 0.5 (10.9)
Fish	19.9 ± 0.5 (11.2)	22.9 ± 0.8 (11.1)	16.9 ± 0.5 (11.3)	8.8 ± 0.4 (6.2)	22.1 ± 0.7 (11.5)	20.9 ± 0.8 (14.8)
Milks	8.3 ± 0.2 (8.4)	8.0 ± 0.2 (7.3)	8.6 ± 0.2 (9.4)	15.7 ± 0.5 (14.1)	7.4 ± 0.2 (7.7)	5.0 ± 0.2 (5.9)
Oils·fats (animal)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)
Others (animal)	0.4 ± 0.0 (0.4)	0.5 ± 0.1 (0.4)	0.4 ± 0.1 (0.3)	0.2 ± 0.1 (0.1)	0.5 ± 0.1 (0.4)	0.3 ± 0.1 (0.2)
Beverages	1.0 ± 0.0 (1.5)	1.1 ± 0.1 (1.6)	0.8 ± 0.1 (1.4)	1.1 ± 0.1 (1.8)	1.1 ± 0.1 (1.7)	0.3 ± 0.0 (0.5)
Alcohols	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)	0.0 ± 0.0 (0.0)
Animal foods	49.5 ± 0.7 (35.4)	54.2 ± 1.0 (34.0)	44.8 ± 0.7 (36.9)	48.5 ± 1.1 (37.1)	51.6 ± 0.8 (35.6)	41.3 ± 1.0 (33.1)
Plant foods	735.7 ± 25.5 (64.5)	796.1 ± 35.9 (65.9)	675.2 ± 25.9 (63.1)	586.4 ± 34.6 (62.9)	739.9 ± 31.3 (64.3)	864.8 ± 46.4 (66.8)

KNHANES, Korea National Health and Nutrition Examination Survey.
[1)]Expresses the mean of the contribution (%) of dietary iodine intake from each food group for each individual.

For children and adolescents under 18 yrs, the primary iodine sources were seaweed (45.5%), milk (14.1%), and eggs (13.6%), with milk contributing more significantly than in other age groups. Conversely, among older individuals aged ≥ 65 yrs, seaweed (39.7%), fish (14.8%), and vegetables (13.7%) were the major contributors to total iodine intake.

Approximately 80% of daily iodine intake came from the top 20 individual foods (**Table 5**). These primary sources varied slightly by sex and age group. The major contributors overall included seaweed (e.g., brown kelp, sea mustard, laver), fish (e.g., Alaska pollock, Pacific cod, fish broth, abalone and anchovy), eggs (chicken and quail), and dairy products (e.g., milk and yogurt).

DISCUSSION

In this study, we applied a newly established database of iodine content in foods to analyze 24-h dietary recall data from the KNHANES 2019–2021. This approach allowed us to assess the dietary iodine intake status of the Korean population. The median daily iodine intake for Koreans aged ≥ 1 yr was 114 µg, equivalent to 123% of the EAR. Overall, half of the population (45.3%) had met their iodine requirements, whereas 44.3% consumed less than the EAR, and 10.4% exceeded the UL. We also analyzed dietary iodine intake after excluding pregnant or lactating women and people with thyroid disease. As these participants were few in number, the results were similar to those including them (**Supplementary Tables 1** and **2**). Excessive intake was particularly notable among children under 12 yrs of age. Approximately two-thirds of the total iodine intake came from plant-based foods, with the primary sources of seaweed, eggs, fish, milk, and grains.

Table 5. Top 20 individual foods and their cumulative contribution to total iodine intake, KNHANES VIII (2019–2021)

Rank	Total			Sex						Age (yrs)								
				Males			Females			1–18			19–64			≥ 65		
	Food	%1)	Cum %2)	Food	%	Cum %	Food	%	Cum %	Food	%	Cum %	Food	%	Cum %	Food	%	Cum %
1	Brown kelp broth	18.1	18.1	Brown kelp broth	19.6	19.6	Brown kelp broth	16.7	16.7	Brown kelp broth	20.8	20.8	Brown kelp broth	18.2	18.2	Brown kelp broth	14.9	14.9
2	Egg	12.4	30.5	Egg	11.8	31.4	Egg	13.0	29.7	Egg	12.5	33.3	Egg	12.8	31.1	Sea mustard	11.2	26.1
3	Laver	10.6	41.1	Laver	9.9	41.3	Laver	11.2	40.9	Laver	11.3	44.6	Laver	10.6	41.7	Egg	10.7	36.8
4	Sea mustard	9.3	50.4	Sea mustard	9.3	50.6	Sea mustard	9.3	50.2	Milk	8.8	53.4	Sea mustard	9.1	50.8	Laver	9.6	46.4
5	Milk	5.3	55.7	Kimchi, baechu	5.3	56.0	Milk	6.0	56.2	Sea mustard	8.6	62.0	Kimchi, baechu	4.9	55.6	Kimchi, baechu	6.5	52.8
6	Kimchi, baechu	4.7	60.5	Milk	4.6	60.6	Kimchi, baechu	4.1	60.3	Brown kelp	4.6	66.6	Milk	4.8	60.4	Soybean paste	5.8	58.6
7	Brown kelp	3.0	63.4	Brown kelp	3.0	63.6	Brown kelp	3.0	63.3	Kimchi, baechu	2.3	69.0	Brown kelp	2.7	63.0	Milk	4.1	62.7
8	Soybean paste	2.4	65.8	Soybean paste	2.3	65.9	Soybean paste	2.4	65.7	Snack	2.0	71.0	Bread	2.0	65.0	Brown kelp	2.8	65.5
9	Bread	1.8	67.7	Green onion	1.8	67.7	Bread	2.0	67.7	Bread	1.7	72.7	Soybean paste	2.0	67.0	Alaska pollock	2.7	68.2
10	Alaska pollock	1.6	69.3	Bread	1.7	69.4	Alaska pollock	1.7	69.3	Ice cream	1.6	74.3	Green onion	1.7	68.6	Green onion	1.9	70.2
11	Green onion	1.6	70.9	Alaska pollock	1.6	71.0	Green onion	1.4	70.8	Pork	1.6	76.0	Alaska pollock	1.6	70.3	Anchovy	1.9	72.1
12	Anchovy	1.1	72.0	Anchovy	1.1	72.1	Yogurt	1.2	71.9	Eggs, quail	1.1	77.1	Snack	1.0	71.3	Kimchi, yeolmu	1.7	73.8
13	Snack	1.1	73.0	Pork	1.1	73.2	Snack	1.1	73.0	Yogurt	1.0	78.1	Anchovy	1.0	72.3	Fish broth	1.7	75.5
14	Fish broth	1.0	74.0	Snack	1.1	74.2	Anchovy	1.1	74.1	Coke	1.0	79.1	Pork	0.9	73.3	Bread	1.4	76.9
15	Pork	1.0	75.0	Ramyeon	1.1	75.3	Fish broth	1.0	75.2	Ice milk	0.9	80.1	Fish broth	0.9	74.2	Yogurt	1.1	78.0
16	Yogurt	0.9	75.9	Coke	1.0	76.2	Ice cream	0.9	76.0	Green onion	0.9	81.0	Ramyeon	0.9	75.1	Fishes, salt-fermented	1.1	79.1
17	Ramyeon	0.8	76.7	Fish broth	0.9	77.2	Pork	0.8	76.9	Cheese	0.9	81.9	Yogurt	0.9	76.0	Crab	1.0	80.1
18	Ice cream	0.8	77.6	Ice cream	0.7	77.9	Kimchi, yeolmu	0.7	77.6	Ramyeon	0.8	82.7	Coke	0.9	76.8	Barley	0.8	80.9
19	Coke	0.8	78.3	Yogurt	0.7	78.6	Crab	0.7	78.3	Soybean paste	0.7	83.4	Ice cream	0.8	77.6	Mackerel	0.8	81.7
20	Kimchi, yeolmu	0.7	79.0	Chicken	0.6	79.3	Cheese	0.6	78.9	Rice	0.7	84.1	Hard shelled Mussel	0.7	78.3	Powdered seasoning	0.6	82.3

KNHANES, Korea National Health and Nutrition Examination Survey.
1)Data are the mean of the contribution (%) of dietary iodine intake from each food for each individual.
2)Data are cumulative contribution (%) of dietary iodine intake.

Most dietary iodine is excreted through urine, and dietary iodine intake strongly correlates with urinary iodine excretion [3,29]. Consequently, urinary iodine concentration is recommended as the gold standard for assessing recent iodine intake [30]. However, this biomarker provides information solely on recent intake and does not capture dietary patterns or sources. Therefore, iodine intake is primarily monitored through dietary surveys, such as 24-h recalls or dietary records.

Dietary iodine intake in Koreans has been reported since the 1990s, consistently indicating high consumption levels. However, earlier studies primarily targeted specific groups, such as patients with thyroid disease and postpartum women at risk of excessive iodine intake, as summarized in **Table 6** [29,31,32]. More recently, efforts have been made to assess iodine intake in the general population of Korea, either through large-scale independent studies [33] or by utilizing raw data from nationally representative surveys, such as the KNHANES [34-37]. Han *et al.* [35] using data from KNHANES 2007–2009, reported a median iodine intake of 375 μg/day (mean: 838 μg/day) among adults aged 20 yrs and older. Similarly, Choi *et al.* [36]

Table 6. Iodine intake status of the Korean population from previous studies

Studies	Data year	Population	Dietary assessment	Iodine intake (μg/d)			Major iodine source (within top 3)
				Calculation	Median (IQR)	Mean	
Chang *et al.* [31]	1991–1993	Thyroid patients and normal adults (n = 177)	24 HR	Foods only	Thyroid patients: 373 Normal subjects: 207	Thyroid patients: 411 Normal subjects: 220	-
Choue *et al.* [32]	1995–1996	Postpartum women (n = 137)	24 HR & FFQ	Foods only	Before delivery: 483 Postpartum 1 week: 3,367 Postpartum 24 week: 1,069	-	-
Kim and Kim [29]	1997–1998	Thyroid patients and normal adults (n = 391)	FFQ	Foods only	-	Thyroid patients: 674 Normal subjects: 469	Seaweed, milk and dairy products, fish
Lee *et al.* [33]	2019	Postpartum women (n = 1,054)	2-d 24 HRs	Foods only	-	All: 2,946 After child birth, 1–2 week: 3,597, 7–8 week: 1,847	Seaweed, fish, milk and dairy products
Ko *et al.* [34]	KNHANES 1998–2014	Adults ≥ 19 yrs (n = 56,818)	1-d 24 HR	Foods only		All: 642_{1998}–236_{2014}	-
Han *et al.* [35]	KNHANES 2007–2009	Adults ≥ 20 yrs (n = 9,998)	1-d 24 HR	Foods only	All: 375 (216–727)	All: 838	Seaweed 66%, salted vegetable 18%, fish 5%
Choi *et al.* [36]	KNHANES 2013–2015	Adults ≥ 20 yrs (n = 5,927)	1-d 24 HRs	Foods only	All: 352 (210–620)	All: 676	Seaweed 56%, salted vegetable 16%, milk and dairy products 7%
Lee *et al.* [37]	KNHANES 2016–2018	≥ 1 yr (n = 21,147)	1-d 24 HRs	Foods only	All: 129 (58–323)	All: 417	Seaweed 77%, milk and dairy products 5%, fish 5%

KNHANES, Korea National Health and Nutrition Examination Survey.

analyzing KNHANES 2013–2015 data, reported a median iodine intake of 352 μg/day (mean: 676 μg/day) for the same age group. In contrast, Lee *et al.* [37] based on KNHANES 2016–2018 data, reported a median iodine intake of 129 μg/day (mean: 417 μg/day) for Koreans aged 1 yr and older. Differences in the variations in population inclusion criteria and the iodine content databases applied to KNHANES data across studies complicate direct comparisons. For instance, some studies excluded individuals consuming more than a certain amount of dried seaweed [37], while others excluded participants based on implausible daily energy intake or other criteria [34-36]. A previous research study [36] found that reports from national organizations analyzing the iodine content of seaweed using the same analytical method varied from about 1,000 μg to 4,000 μg, depending on the source. Despite these differences, Koreans' iodine intake has generally been observed to be high, with a slight decline in recent years. This decline was also noted in a study analyzing trends in iodine intake using KNHANES data from 1998 to 2014 [34], which found that the mean daily iodine intake among adults aged 19 yrs and older decreased significantly from 642 μg in 1998 to 236 μg in 2014.

In Korea, the iodine intake of lactating women is particularly notable, as they traditionally consume seaweed soup (*miyeokguk*) to support breast milk production and recovery after childbirth. A recent nationwide survey of postpartum women found that their mean iodine intake gradually decreased from 3,597 μg at 1–2 weeks postpartum to 1,847 μg at 7–8 weeks postpartum [33]. However, these values are still close to the UL of 2,400 μg/day for lactating women, as recommended in Dietary Reference Intakes for Koreans [2]. The estimated iodine intake of Koreans in our study was consistent with previous findings, showing a median intake higher than the EAR and a distribution heavily skewed to the right.

The iodine intake of Koreans does not appear exceptionally high compared to other countries. For easy comparison, we presented studies reporting iodine intake in other

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countries in **Table 7**. Unsurprisingly, Japan, with its high consumption of seaweed and seafood, had the highest iodine intake among the countries studied [38-41]. In our study, as well as in previous studies on Koreans [29,31-33,35-37], the Korean iodine intake was lower than that of the Japanese. In both Japan and Korea, people consume various seaweeds and use kelp broth—a highly concentrated source of iodine—as a flavor-enhancing ingredient in cooking. However, kelp broth is often overlooked in dietary surveys due to its low-calorie content, even though it is extremely high in iodine. Interestingly, even studies excluding kelp broth have reported substantial iodine intake in Japan [39].

Meanwhile, iodine intake in Korea is not higher than that in other countries such as Australia [42], the Netherlands [43], the United Kingdom [44], the United States (U.S.) [45,46], and Norway [47,48]. In these regions, inadequate iodine intake is a significant nutritional concern due to the low iodine content of natural foods and the insufficient consumption of iodine-rich seaweed. To address this issue, some governments have implemented iodine fortification programs, including mandatory fortification of salt or the use of iodized salt in bread production. As a result, the total daily iodine intake of the population in these countries has been shown to be adequate [7,43,47]. However, the iodine intake reported in countries such as the U.S., the Netherlands, and Norway includes estimates from all possible sources, such as iodized salt, drinking water, and dietary supplements, not just food [43,45,47]. If we consider only food sources, Koreans' iodine intake is likely lower than that of the Japanese but slightly higher than that of populations in the countries mentioned above.

Our study found that seaweed, eggs, fish, vegetables, and milk were the primary sources of iodine intake among Koreans, aligning with findings from previous studies on the Korean

Table 7. Iodine intake in other countries from previous studies

Country	Data year	Population		Dietary assessment	Iodine intake (ug/d)			Major iodine source (within top 3)
		Age	No.		Calculation	Median (IQR)	Mean	
Japan [38]	1996–1997	45–77 yrs	113	12-d DRs	Foods only	-	M: 2,550 F: 2,160	Seaweed, milk and milk products, fish and shell fish (included kelp broth)
Japan [39]	1996–1997	Mid 40s[1)]	98	28-d DRs	Foods only	M: 312 (191–551) F: 413 (293–625)	M: 670 F: 539	Kelp 76.7%, hijiki 12.1% (ignored soup stock)
Japan [40]	2013	20–69 yrs	380	4-d DRs	Foods only	M: 698 (396–1,310) F: 511 (282–1,080)	-	(Included soup stock)
Japan [41]	2015	30–76 yrs	240	16-d DRs	Foods only	M: 1,031 (442–1,732) F: 857 (532–1,414)	M: 1,572 F: 1,414	Kelp 60%, soup stock 30%, hijiki 5% (included soup stock)
Australia [42]	NNPAS, 2011–2012	≥ 2 yrs	7,735	2-d 24 HRs	Foods only	All: $152_{4\text{–}8\,y}$–$177_{14\text{–}18\,y}$	-	Cereal and cereal products 29%, milk products and dishes 26%, non-alcoholic beverages 15%
Netherland [43]	DNFCS, 2007–2010	7–69 yrs	3,870	2-d 24 HRs	Foods, salt, and DS	M: 233 (194–274) F: 188 (158–219)	-	Bread 38%, dairy products 14%, discretionary iodized salt 14%
UK [44]	NDNS, 2014–2017	≥ 1.5 yrs	3,676	4-d DRs	Foods only	M: 136 (94–195) F: 114 (85–159)	-	-
USA [45]	NHANES, 2003–2010	≥ 2 yrs	31,352	2-d 24 HRs	Foods, salt, DS (except kelp-containing DS), drinking water	M: $307_{1\text{–}3y}$–$371_{14\text{–}18y}$ F: $241_{14\text{–}18y}$–$304_{1\text{–}3y}$	M: $317_{1\text{–}3y}$–$394_{14\text{–}18y}$ F: $254_{14\text{–}18y}$–$320_{1\text{–}3y}$	Foods, drinking water, salt used for cooking; for adults aged 19–30 yrs, nearly 80% of iodine intake came from foods.
USA [46]	NHANES, 2008–2012	≥ 0.5 yrs		2-d 24 HRs	Foods only	-	All: 216	Milk and dairy 49%, grain 17%, mixture 17%
Norway [47]	2014–2015	≥ 3 yrs	276	2-d DRs	Foods and DS	All: 101 (75–150)	All: 119	Milk and dairy 40–60%, seafood, egg; for vegans, DS up to 90%
Norway [48]	Tromsø Study, 2015–2016	40–69 yrs	493	FFQ	Foods only	M: 317 (228–408) F: 263 (200–355)		-

NDNS, National Diet and Nutrition Survey; NNPAS, National Nutrition and Physical Activity Survey; DNFCS, Dutch National Food Consumption Survey; DR, Dietary record; 24 HR, 24-h dietary recall; FFQ, Food Frequency Questionnaire; DS, dietary supplement.

[1)]Only the mean age was presented, 45.0 for men and 46.7 for women.

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population, as summarized in **Table 6** [7,29,35,37]. The main food contributors to total iodine intake showed minimal difference by sex; however, there were notable variations by age group. For example, seaweed is a major source of iodine for children, contributing 55% of the daily intake among those aged 1–5 yrs (data not shown). Still, the relative contribution of milk was more significant than in other age groups. In contrast, seaweed, fish, and vegetables were the primary sources in older people, likely reflecting age-related dietary patterns [8]. When comparing food sources by country, Japan similarly derives its iodine intake predominantly from seaweed, with a larger contribution from this source than Korea. In contrast, North America and Europe rely on entirely different food sources for iodine (**Table 7**). For instance, a study of the U.S. population estimated iodine intake from all possible sources, including food, drinking water, dietary supplements, and salt. It showed that for adults aged 19–30 yrs, only about 3-quarters of their total daily iodine intake came from food, with the rest from non-food sources [45]. Another study analyzed the contribution of food groups to daily iodine intake and found that the U.S. population (6 mon or older) predominantly received dietary iodine from milk and dairy products (49%), grains including starches and baked goods (17%), and mixed dishes (17%) [46]. Similarly, in Australia, the Netherlands, and Norway, milk, dairy, and cereal products, including bread, are the major contributors to daily iodine intake [42-44,47].

The distribution of iodine intake also varied significantly across populations (**Tables 6** and **7**). In Japan and Korea, where seaweed is the main source of iodine, the distribution is heavily skewed to the right, resulting in a large gap between the median and mean iodine intake [35-37,39-41]. Conversely, the mean and median iodine intakes in regions such as the U.S. and Europe are relatively similar, with less pronounced variations [43-45,47,48]. This difference is likely attributable to the distinct dietary patterns in these regions. In Korea and Japan, the high iodine content of seaweed and its widespread consumption create a broader intake distribution. In contrast, the reliance on iodized salts and fortified foods such as milk, dairy products, grains and cereal products in the U.S. and Europe lead to more uniform iodine intake levels across populations.

A previous study from Japan analyzed the ratio of within-person to between-person variance in several trace minerals and found that dietary iodine exhibited the highest ratio, presumed to be due to a specific contributor: seaweed [39]. The situation in Korea is likely similar; thus, the proportions of excessive and insufficient iodine intake may have been overestimated in this study, which utilized a one-day dietary survey of the KNHANES.

This study provides updated insights into iodine intake in Korea by developing a database based on the KNHANES for estimation. However, this study had some limitations. First, as mentioned earlier, the assessment of iodine intake relied on one-day, 24-h dietary recall data, which may have overestimated the proportions of insufficient and excessive intake [49]. Second, we compiled a food iodine content database by reviewing domestic and international data following standardized principles. Nevertheless, the iodine content in most foods, except for certain foods such as seaweed, is very low, and its concentration in seaweed can vary significantly based on the time and location of collection [50], potentially limiting database accuracy. The results of this study are based on the KDCA's policy research project 'Development of database of iodine for KNHANES's data processing' and may differ from the iodine intake announced by the KDCA in the future. Third, although iodine is derived from multiple sources— including food, drinking water, and dietary supplements—this study only assessed iodine intake from food. Dietary surveys encompassing all possible sources and multi-day assessments are necessary to gain a more comprehensive understanding of iodine intake among Koreans.

In conclusion, Koreans' median dietary iodine intake appears to be adequate. However, a significant proportion of the population exhibits insufficient or excessive iodine intake. Further studies should aim to estimate the usual dietary iodine intake using multi-day assessments to capture population-level intake patterns. Additionally, research should explore strategies to mitigate problematic iodine intake and achieve optimal nutritional status across diverse demographic groups.

SUPPLEMENTARY MATERIALS

Supplementary Table 1

Relative dietary iodine intake (% EAR) of Korean females, after excluding pregnant or lactating women

Supplementary Table 2

Adequacy of dietary iodine intake of Korean females, after excluding pregnant or lactating women

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