Nutr Res Pract. 2026 Jun;20(3):476-489
https://doi.org/10.4162/nrp.2026.20.3.476
pISSN 1976-1457·eISSN 2005-6168

Research Paper

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Dietary intake and food sources of choline in Koreans: findings from Korea National Health and Nutrition Examination survey 2018–2022

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Received: Oct 28, 2025
Revised: Dec 1, 2025
Accepted: Jan 6, 2026
Published online: Feb 6, 2026

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Funding
This research was supported by a grant (25192MFDS002) from Ministry of Food and Drug Safety in 2025.

ABSTRACT

BACKGROUND/OBJECTIVES: Choline is an essential nutrient that plays important roles in the biological functioning of the human body. Insufficient choline intake has been reported worldwide; however, data from the Korean population are limited. This study aimed to estimate the dietary choline intake and identify its major sources in Koreans.
SUBJECTS/METHODS: We analyzed the 24-h dietary recall data of 31,789 participants aged ≥ 1 yr from the Korea National Health and Nutrition Examination Survey 2018–2022. Dietary choline intake was calculated using the newly developed choline content of foods. Dietary adequacy was evaluated by comparing sex- and age-specific adequate intake (AI) and tolerable upper intake level (UL).
RESULTS: The mean dietary choline intake was 591 mg/day (median: 544 mg/day) in Koreans aged ≥ 1 yr, which was 143% (median: 132%) of the AI. Approximately 70% of Koreans had intakes between the AI and UL, but nearly 30% consumed less than the AI. Dietary choline intake below the AI was more prevalent among females and older individuals. Three-fifths of the dietary choline intake came from plant-based foods. The main food groups that contributed to dietary choline intake were grains (45.2%), eggs (13.4%), meat (12.2%), fish (7.3%), and vegetables (5.6%).
CONCLUSION: Although specific subpopulations were observed to have dietary choline intake below the AI, the overall dietary choline intake among Koreans appeared to be sufficient. This study estimated the dietary choline intake from foods alone. Further research is required to assess the intake of choline-containing compounds and dietary supplements and gain a more comprehensive understanding of choline intake in the Korean population.

Keywords: Choline; diet; nutrition surveys; South Korea; food analysis

INTRODUCTION

Choline is a quaternary ammonium compound that plays important roles in cell membrane synthesis, neurotransmission, one-carbon metabolism, lipid transport, and lipid metabolism [1,2]. Choline was discovered in 1849, isolated from pig bile [3], and named in 1862 after the

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

Author Contributions
Conceptualization: Shim JS, Shim E, Park E; Data curation: Shim JS, Choi M; Formal analysis: Shim JS; Funding acquisition: Park E; Methodology: Shim JS; Supervision: Park E; Visualization: Shim JS; Writing - original draft: Shim JS; Writing - review & editing: Shim JS, Choi M, Shim E, Park E.

Greek word *chole*, meaning bile. In the mid-1900s, choline was recognized as an essential dietary compound for animals, as evidence accumulated that it functions as a component of the neurotransmitter acetylcholine, and its deficiency in animal studies leads to fatty liver, hepatic cancer, atheromatous changes, and impaired growth, and although choline can be synthesized in the body, the amount produced is not sufficient to meet physiological requirements, thus necessitating dietary intake [4,5].

However, for several decades, it was believed that humans, unlike animals, did not need to obtain choline through their diet [5,6]. Recently, choline has been recognized as an essential nutrient. Interest in the human body's choline requirement began to grow around 1980, following the establishment of the importance of choline in early life and its impact on human brain development and cognitive function [5,7,8]. Recognition of choline as an essential nutrient for humans began to shift following a notable 1991 study by Zeisel *et al.* [6]. In that clinical trial, healthy men fed a choline-deficient diet developed fatty liver and liver damage, both of which resolved when choline was replenished in the diet. Similar findings were observed in a subsequent study that included women, in which a choline-deficient diet led to fatty liver or muscle damage in almost all men and postmenopausal women; however, these organ dysfunctions were resolved when choline was provided in the diet [9]. The effects of dietary choline on the human body have also been confirmed by studies examining the changes before and after choline supplementation in patients receiving total parenteral nutrition devoid of choline [1,10,11], demonstrating that the endogenous synthesis of choline is not sufficient to meet human requirements and that choline needs to be ingested with food.

Although the essentiality of dietary choline intake had been recognized, the establishment of an estimated average requirement was hindered by a lack of data. Moreover, data were scarce regarding the choline content of foods and the choline intake in the general population, making it difficult to establish the dietary reference intake (DRI) for choline. Under these circumstances, in 1998, the U.S. Institute of Medicine of the National Academy of Sciences set adequate intake (AI) levels for choline based on the experimental evidence from the aforementioned depletion-repletion study [6], although these references were derived from a single, small-scale study [1]. A few years later, studies were conducted to determine whether these established values were within the acceptable range for human choline intake. In an ad libitum feeding study of healthy adults, the mean choline intake closely approximated the established AI [12], indicating that the AI may serve as a reasonable estimate of actual intake in the general population. In 2006, Australia and New Zealand established their dietary reference values for choline based on the same evidence used by the U.S. [13]. That approach was considered appropriate, as their established AIs fell within the range between ineffective and effective amounts for preventing deficiency, as observed in studies involving individuals receiving total parenteral nutrition. Estimation of dietary choline intake has become possible since the U.S. Department of Agriculture (USDA) released its database of choline content in foods in 2008 [14]. Since then, the database has been combined with dietary survey data to estimate people's actual choline intake [15-18]. Considering the choline intake in European populations from national dietary surveys and the findings in a depletion-repletion study [9,18], the European Food Safety Authority set dietary reference values for choline in 2016 [2]. Now, many countries, including China and Taiwan, have established dietary reference values for choline to manage people's dietary intakes [19,20].

Worldwide, dietary choline intake appears to be insufficient. A recent narrative review analyzed the current trends in choline intake in 9 European and 8 non-European countries

[21]. Dietary choline did not meet the AI among various population groups, including adults and pregnant women, in both European and non-European populations. Previous studies estimated choline intake in Koreans [22-24], all of which were conducted 2 decades ago. One study evaluated the actual choline intake of adults in their 20s and 30s [22], and another study estimated choline intake levels using the choline content of foods commonly consumed by Koreans and data on per capita food intake [23]. In these studies, it seemed unlikely that the choline intake in Koreans was insufficient.

With the increasing demand for the establishment of a choline DRI for Koreans, along with interest in the health impact of choline [25,26], the Korean Nutrition Society has established DRIs for choline for Koreans in 2025 [27]. This study aimed to estimate the current status of dietary choline intake in Koreans and identify the major sources using a newly constructed choline database.

SUBJECTS AND METHODS

Data source and study population

The Korea Disease Control and Prevention Agency (KDCA) conducts the Korea National Health and Nutrition Examination Survey (KNHANES), a nationwide cross-sectional survey of non-institutionalized Koreans aged ≥ 1 yr. For the present study, we used data from the KNHANES 2018–2022. The KNHANES study protocol was approved by the Institutional Review Board (IRB) of the KDCA (IRB No. 2018-01-03-P-A, 2018-01-03-C-A, 2018-01-03-2C-A, 2018-01-03-5C-A, and 2018-01-03-4C-A). Written informed consent was obtained from all participants. Raw data are available on the KNHANES website (https://knhanes.kdca.go.kr, accessed March 7, 2025). Additional details are provided elsewhere [28,29].

Among all participants in KNHANES 2018–2022 (n = 36,816), this study included 31,789 who completed the 24-h dietary recall survey.

Dietary assessment

Dietary intake was assessed using a 24-h dietary recall. Trained dietitians interviewed all participants and collected details about their diet on the day before the survey, such as when, where, what, and how much they had consumed over the 24 h of the previous day. The raw data included information on the participants' dietary intakes of energy and nutrients [29]; however, dietary choline intake was not included. This is because the food composition table used to process the nutrition survey data did not include choline content in the foods. Further details regarding dietary assessment in the KNHANES are available elsewhere [28,30].

Choline composition database and dietary choline intake

To build a database of the choline content of foods reported as consumed in the KNHANES 2018–2022, we gathered information on the choline content of foods from previously published materials. Fortunately, we found domestically published data, including a research report and an academic paper on the choline content of foods consumed by Koreans, all of which were conducted by Chung *et al.* [31-33]. The USDA databases [14], the Food Data Central website [34], and an Australian database [35] were searched for international data. As most foods in the Australian database were sourced from USDA data [35], we considered the USDA and Food Data Central data as the main international references. To obtain adequate and reliable food composition data, we followed the principles and guidelines for producing, managing, and using food composition data proposed by Greenfield and Southgate [36]. The database was constructed by matching the descriptive information (e.g., name, physical state, and extent of preparation) of foods reported for consumption in the KNHANES with the descriptive information of foods analyzed for choline content from previous data sources. Among the available references, domestic food analysis values and recent analysis values were selected and applied first. If there were no analysis values, the analysis values of similar foods were borrowed, and foods that were difficult to recognize as similar foods were imputed values calculated using recipes (for dishes) and ingredient mixing ratios (for processed foods). We also consulted 2 external experts during the database construction process to improve the database quality. Our choline content database covered 98.6% of 4,069 food items reported in KNHANES, and the foods that were not included were those that were rarely consumed and not included as major food sources of choline, such as pine needles, silkworms, and some tropical fruits like durian. Approximately three-fourths of food items were sourced domestically, with the remaining from international sources. Among all the food items, 60.4% were fully matched, 34.0% were similarly matched, and 3.4% were composed of recipes and ingredient ratio calculations.

Dietary choline intake was calculated by applying the choline database to the KNHANES 24-h dietary recall raw data.

Statistical analysis

Absolute dietary choline intake was presented as percentiles (2.5th, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97.5th) along with the mean and SE. We also presented the relative choline intake as a percentage of the AI for each sex and age, calculated by dividing the choline intake by the corresponding AI value suggested by the DRI for Koreans 2025 [27]. We reflected on the increased needs of pregnant and lactating women during pregnancy and breastfeeding. The adequacy of choline intake was presented as the prevalence of insufficient intake (below the AI), sufficient intake (AI to [tolerable upper intake level] UL), and excessive intake (above the UL). Dietary choline intake was presented for the total population and further stratified by sex and age (1–2, 3–5, 6–8, 9–11, 12–14, 15–18, 19–29, 30–49, 50–64, 65–74, and ≥ 75 yrs).

The raw data included information on all foods consumed by the participants, along with their categorization into 20 food groups and 571 individual foods. To identify the major dietary sources of choline, we calculated the intake of each food group and its percentage contribution to the choline intake. Similarly, we calculated the contribution of each food item to choline intake and identified the top 20 foods. The contribution was presented for the total population, as well as stratified by sex and age groups (1–18, 19–64, and ≥ 65 yrs).

All statistical analyses were performed using the SAS software (version 9.4; SAS Institute, Cary, NC, USA). The sampling weights and complex sampling design of the KNHANES were accounted for in all the analyses.

RESULTS

Absolute and relative intake of dietary choline

Table 1 shows the distribution of absolute dietary choline intake and mean ± SE for Koreans. For the total population aged ≥ 1 yr, the dietary choline intake ranged from 191 to 1,274 mg/

https://doi.org/10.4162/nrp.2026.20.3.476

Table 1. Absolute dietary choline intake (mg/day) of Koreans, Korea National Health and Nutrition Examination Survey 2018–2022

Age group (yrs)	Number	Percentile									Mean ± SE
		2.5	5	10	25	50	75	90	95	97.5	
All (≥ 1)	31,789	191	231	285	393	544	733	949	1,110	1,274	591 ± 2
Adults (≥ 19)	26,201	193	234	291	402	554	745	960	1,125	1,301	601 ± 2
Age group											
1–2	532	134	164	195	244	334	422	524	572	663	348 ± 7
3–5	941	177	199	237	306	397	509	648	737	806	424 ± 6
6–8	1,099	198	245	278	361	480	599	731	878	1,027	504 ± 8
9–11	1,107	229	260	300	397	538	693	864	981	1,120	566 ± 8
12–14	920	219	271	327	433	571	775	984	1,119	1,232	623 ± 11
15–18	989	190	230	290	389	562	777	1,003	1,117	1,283	617 ± 12
19–29	3,129	180	221	272	391	556	765	1,018	1,216	1,432	614 ± 6
30–49	8,022	208	251	310	424	578	781	1,001	1,175	1,337	629 ± 4
50–64	7,415	200	243	303	419	566	747	964	1,117	1,255	609 ± 4
65–74	4,404	193	225	285	386	524	687	857	987	1,098	556 ± 5
≥ 75	3,231	156	196	236	323	443	593	759	862	977	477 ± 5
Males (≥ 1)	14,202	234	283	348	469	629	831	1,056	1,234	1,391	677 ± 3
Adults (≥ 19)	11,303	246	299	369	488	644	845	1,075	1,255	1,418	694 ± 4
Age group											
1–2	265	144	164	201	256	333	428	529	580	671	353 ± 10
3–5	486	188	213	254	325	420	541	683	776	865	447 ± 9
6–8	532	244	263	311	401	502	627	800	987	1,126	544 ± 12
9–11	597	225	274	331	442	575	728	927	1,054	1,211	605 ± 13
12–14	506	286	321	376	485	646	835	1,050	1,161	1,329	691 ± 15
15–18	513	203	260	319	481	663	900	1,078	1,238	1,352	701 ± 18
19–29	1,474	222	278	351	475	643	861	1,157	1,378	1,560	710 ± 10
30–49	3,432	261	322	387	514	683	884	1,122	1,291	1,448	725 ± 6
50–64	3,143	256	315	384	502	655	852	1,061	1,228	1,385	698 ± 6
65–74	1,897	246	292	353	458	590	763	942	1,063	1,195	628 ± 7
≥ 75	1,357	201	248	303	411	533	678	837	948	1,050	559 ± 7
Females (≥ 1)	17,587	167	206	251	343	470	626	800	924	1,045	505 ± 2
Adults (≥ 19)	14,898	167	206	252	345	474	632	807	930	1,050	509 ± 2
Age group											
1–2	267	126	162	192	236	336	418	501	569	635	342 ± 10
3–5	455	164	193	222	292	383	471	604	669	737	398 ± 9
6–8	567	167	207	256	335	448	574	686	744	872	464 ± 8
9–11	510	230	248	282	368	492	639	806	887	989	526 ± 11
12–14	414	166	229	276	376	508	682	879	986	1,196	549 ± 14
15–18	476	181	215	262	354	484	655	808	952	1,034	520 ± 12
19–29	1,655	154	189	237	325	467	640	820	957	1,070	507 ± 7
30–49	4,590	179	221	270	359	490	653	833	961	1,070	527 ± 4
50–64	4,272	177	215	265	361	492	648	815	938	1,080	523 ± 4
65–74	2,507	171	202	243	344	464	610	759	867	986	491 ± 5
≥ 75	1,874	142	184	217	293	387	529	676	777	890	425 ± 6

Values are presented as percentiles (2.5th–97.5th) and mean±SE. All estimates were derived from survey-weighted analyses accounting for the complex sampling design, using integrated weights for 2018–2022.

day (2.5th–97.5th percentile), with median and mean intakes of 544 mg/day and 591 mg/day, respectively. The dietary choline intake was slightly skewed to the right in all sex and age subgroups. Overall, males had a higher dietary choline intake than females, and in adults aged > 30 yrs, choline intake decreased with age.

Table 2 shows the relative intake compared with the sex- and age-specific AIs. Among the total population, the relative intake compared with the AI ranged from 47 to 301% (2.5th–97.5th percentile), with a median intake of 132%. On average, Koreans consume 143% of the AI for choline. Similar to the absolute choline intake, the relative intake was slightly skewed to the right in all groups, with males having a higher relative intake than females, and both decreased with age.

Table 2. Relative dietary choline intake (% AI) of Koreans, Korea National Health and Nutrition Examination Survey 2018–2022

Age group (yrs)	AI[1)] (mg/d)	Percentile									Mean ± SE
		2.5	5	10	25	50	75	90	95	97.5	
All (≥ 1)		47	58	71	97	132	176	227	265	301	143 ± 1
Adults (≥ 19)		46	57	70	94	128	169	215	250	284	137 ± 1
Age group											
1–2		84	103	122	153	209	264	328	358	415	217 ± 5
3–5		93	105	125	161	209	268	341	388	424	223 ± 3
6–8		79	95	109	142	187	235	286	339	395	197 ± 3
9–11		69	77	88	119	158	201	256	288	326	166 ± 2
12–14		56	66	78	102	136	182	232	257	304	147 ± 2
15–18		43	55	67	94	131	178	219	253	281	140 ± 2
19–29		43	53	66	91	127	173	225	269	308	139 ± 1
30–49		50	60	74	99	133	176	223	258	292	143 ± 1
50–64		48	59	73	98	131	172	216	247	283	140 ± 1
65–74		47	55	67	91	121	158	195	222	251	128 ± 1
≥ 75		38	48	58	79	104	137	174	199	228	112 ± 1
Males (≥ 1)		52	64	78	104	139	184	236	277	316	151 ± 1
Adults (≥ 19)		51	62	77	102	134	176	224	262	295	145 ± 1
Age group											
1–2	160	90	103	126	160	208	267	331	363	420	221 ± 6
3–5	190	99	112	134	171	221	285	359	409	455	235 ± 5
6–8	260	94	101	120	154	193	241	308	380	433	209 ± 5
9–11	350	64	78	95	126	164	208	265	301	346	173 ± 4
12–14	450	64	71	83	108	144	186	233	258	295	154 ± 3
15–18	480	42	54	67	100	138	188	224	258	282	146 ± 4
19–29	480	46	58	73	99	134	179	241	287	325	148 ± 2
30–49	480	54	67	81	107	142	184	234	269	302	151 ± 1
50–64	480	53	66	80	105	137	178	221	256	289	145 ± 1
65–74	480	51	61	73	95	123	159	196	221	249	131 ± 1
≥ 75	480	42	52	63	86	111	141	174	198	219	116 ± 1
Females (≥ 1)		44	54	67	91	125	169	218	252	286	136 ± 1
Adults (≥ 19)		43	53	64	88	121	162	207	238	269	130 ± 1
Age group											
1–2	160	79	101	120	147	210	261	313	355	397	214 ± 6
3–5	190	86	102	117	154	201	248	318	352	388	210 ± 5
6–8	250	67	83	103	134	179	230	274	298	349	186 ± 3
9–11	330	70	75	86	111	149	194	244	269	300	160 ± 3
12–14	390	43	59	71	96	130	175	225	253	307	141 ± 4
15–18	390	46	55	67	91	124	168	207	244	265	133 ± 3
19–29	390	39	48	61	83	119	164	210	245	274	130 ± 2
30–49	390	46	56	69	91	125	166	212	245	274	134 ± 1
50–64	390	45	55	68	93	126	166	209	241	277	134 ± 1
65–74	390	44	52	62	88	119	156	195	222	253	126 ± 1
≥ 75	390	37	47	56	75	99	136	173	199	228	109 ± 1

Values are presented as percentiles (2.5th–97.5th) and mean±SE. All estimates were derived from survey-weighted analyses accounting for the complex sampling design, using integrated weights for 2018–2022.
AI, adequate intake.
[1)]Sex- and age-specific AI suggested by the Korean Dietary Reference Intake 2025.

Adequacy of dietary choline intake

Table 3 shows the prevalence of dietary choline intake among Koreans categorized by the AI and UL: intake below the AI, intake between the AI and UL, and intake above the UL. For the total population, 7 out of 10 people had dietary choline intake between the AI and UL, while the remaining 3 had intake below the AI. Overall, intake above the UL were found in only 2–3% of children aged 1–2 and 6–8 yrs, but were rarely observed in other age groups. By sex, females exhibited a higher prevalence of intake below the AI than males, and this was consistently observed across all age groups. By age group, intake below the AI was more noticeable in older people. For adults aged ≥ 75 yrs, nearly half consumed dietary choline below the AI.

Table 3. Adequacy of dietary choline intake of Koreans, Korea National Health and Nutrition Examination Survey 2018–2022

Age group (yrs)	Number	Prevalence (%) of intake		
		< AI[1)]	AI–UL[2)]	≥ UL
All (≥ 1)	31,789	27.0 (0.4)	72.9 (0.4)	0.1 (0.0)
Adults (≥ 19)	26,201	29.1 (0.4)	70.9 (0.4)	-[3)]
Age group				
1–2	532	4.2 (0.9)	93.6 (1.1)	2.2 (0.6)
3–5	941	3.4 (0.6)	96.2 (0.6)	-
6–8	1,099	6.2 (0.8)	90.9 (1.0)	2.9 (0.6)
9–11	1,107	14.6 (1.3)	85.3 (1.3)	-
12–14	920	23.1 (1.7)	76.6 (1.7)	-
15–18	989	28.8 (1.6)	71.0 (1.6)	-
19–29	3,129	30.7 (1.0)	69.3 (1.0)	-
30–49	8,022	25.8 (0.6)	74.2 (0.6)	-
50–64	7,415	26.3 (0.6)	73.7 (0.6)	0
65–74	4,404	32.1 (0.9)	67.9 (0.9)	-
≥ 75	3,231	46.4 (1.1)	53.6 (1.1)	0
Males (≥ 1)	14,202	22.2 (0.4)	77.6 (0.4)	0.2 (0.0)
Adults (≥ 19)	11,303	23.9 (0.5)	76.1 (0.5)	-
Age group				
1–2	265	3.9 (1.3)	93.9 (1.5)	-
3–5	486	3.3 (0.8)	96.3 (0.9)	-
6–8	532	4.7 (1.0)	90.7 (1.4)	4.6 (1.1)
9–11	597	12.1 (1.5)	87.7 (1.5)	-
12–14	506	18.6 (2.1)	80.7 (2.1)	-
15–18	513	24.7 (2.1)	75.0 (2.2)	-
19–29	1,474	25.7 (1.3)	74.3 (1.3)	-
30–49	3,432	20.4 (0.8)	79.6 (0.8)	0
50–64	3,143	22.1 (0.8)	77.9 (0.8)	0
65–74	1,897	28.6 (1.3)	71.3 (1.3)	-
≥ 75	1,357	39.9 (1.5)	60.1 (1.5)	0
Females (≥ 1)	17,587	31.8 (0.5)	68.1 (0.5)	0.1 (0.0)
Adults (≥ 19)	14,898	34.3 (0.5)	65.7 (0.5)	-
Age group				
1–2	267	4.4 (1.3)	93.3 (1.4)	-
3–5	455	3.6 (1.0)	96.1 (1.0)	-
6–8	567	7.7 (1.2)	91.2 (1.3)	-
9–11	510	17.3 (2.0)	82.7 (2.0)	0
12–14	414	28.0 (2.6)	72.0 (2.6)	0
15–18	476	33.6 (2.4)	66.4 (2.4)	0
19–29	1,655	36.3 (1.4)	63.7 (1.4)	0
30–49	4,590	31.5 (0.8)	68.5 (0.8)	-
50–64	4,272	30.5 (0.8)	69.5 (0.8)	0
65–74	2,507	35.3 (1.1)	64.7 (1.1)	0
≥ 75	1,874	50.5 (1.4)	49.5 (1.4)	0

Values are presented as percentages (SE) from survey-weighted analyses accounting for the complex sampling design, using integrated weights for 2018–2022.
AI, adequate intake; UL, tolerable upper intake level.
[1)]AI (mg/d) values by age group and sex suggested by the Korean Dietary Reference Intake 2025 are as follows: 1–2 yrs, 160 (both sexes); 3–5 yrs, 190 (both sexes); 6–8 yrs, 260 (M), 250 (F); 9–11 yrs, 350 (M), 330 (F); 12–14 yrs, 450 (M), 390 (F); 15+ yrs, 480 (M), 390 (F); and for pregnant and lactating women, 470 and 500, respectively.
[2)]UL (mg/d) values by age group and sex suggested by the Korean Dietary Reference Intake 2025 are as follows: 1–2 yrs, 700 (both sexes); 3–8 yrs, 1,000 (both sexes); 9–11 yrs, 1,500 (both sexes), 12–14 yrs, 2,000 (both sexes); 15–18 yrs, 2,500 (M), 2,000 (F); 19+ yrs, 3,000 (M), 2,500 (F); for pregnant and lactating women, both 2,500.
[3)]Does not present estimates with fewer than 10 subjects.

Dietary sources of choline intake

Table 4 shows the choline intake from each food group and its contribution to the daily intake. For the total population, approximately two-thirds of the daily choline intake came from plant-based foods. Of the 20 food groups, the top 5 contributing to daily choline

https://doi.org/10.4162/nrp.2026.20.3.476

Table 4. Dietary choline intake of Koreans from food groups and their contribution to daily choline intake, Korea National Health and Nutrition Examination Survey 2018–2022

Food groups	Total		Sex				Age (yrs)					
			Males		Females		1–18		19–64		≥ 65	
	Mean ± SE[1)]	%[2)]	Mean ± SE	%	Mean ± SE	%	Mean ± SE	%	Mean ± SE	%	Mean ± SE	%
Grains	256.2 ± 1.1	45.2	297.2 ± 1.6	45.8	215.2 ± 1.2	44.6	239.7 ± 2.3	45.9	260.5 ± 1.4	43.6	253.9 ± 1.8	51.3
Potatoes·starches	7.6 ± 0.2	1.4	7.9 ± 0.2	1.2	7.3 ± 0.2	1.6	8.4 ± 0.4	1.6	7.6 ± 0.2	1.4	6.7 ± 0.3	1.4
Sugars·sweet	1.0 ± 0.0	0.2	1.1 ± 0.1	0.2	0.9 ± 0.0	0.2	1.5 ± 0.1	0.3	1.0 ± 0.1	0.2	0.4 ± 0.0	0.1
Pulses	18.8 ± 0.3	3.3	20.6 ± 0.4	3.1	17.0 ± 0.3	3.4	11.3 ± 0.4	2.1	18.7 ± 0.3	3.1	26.5 ± 0.6	5.2
Nuts·seeds	3.1 ± 0.1	0.5	3.3 ± 0.1	0.5	2.9 ± 0.1	0.6	1.4 ± 0.1	0.3	3.2 ± 0.1	0.5	4.0 ± 0.2	0.8
Vegetables	31.5 ± 0.2	5.6	35.6 ± 0.3	5.5	27.3 ± 0.2	5.7	16.7 ± 0.3	3.2	33.8 ± 0.2	5.8	35.9 ± 0.5	7.1
Mushrooms	2.1 ± 0.1	0.4	2.1 ± 0.1	0.3	2.1 ± 0.1	0.4	1.6 ± 0.1	0.3	2.3 ± 0.1	0.4	1.6 ± 0.1	0.3
Fruits	14.9 ± 0.4	2.7	13.0 ± 0.4	2.0	16.8 ± 0.5	3.3	10.5 ± 0.4	2.2	14.6 ± 0.4	2.5	20.7 ± 0.9	3.8
Seaweed	3.2 ± 0.0	0.6	3.4 ± 0.1	0.5	3.0 ± 0.1	0.6	2.9 ± 0.1	0.6	3.2 ± 0.1	0.6	3.4 ± 0.1	0.7
Seasonings	15.5 ± 0.2	2.6	18.6 ± 0.4	2.7	12.5 ± 0.2	2.5	11.0 ± 0.5	2.0	17.1 ± 0.3	2.7	13.2 ± 0.3	2.5
Oils·fats (plant)	0.1 ± 0.0	0.0	0.1 ± 0.0	0.0	0.1 ± 0.0	0.0	0.1 ± 0.0	0.0	0.1 ± 0.0	0.0	0.1 ± 0.0	0.0
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
Meat	73.2 ± 0.8	12.2	93.2 ± 1.3	13.7	53.2 ± 0.7	10.7	75.1 ± 1.6	14.0	82.4 ± 1.0	13.3	32.3 ± 0.8	6.0
Eggs	93.2 ± 1.1	13.4	101.4 ± 1.6	12.8	85.0 ± 1.2	14.1	95.2 ± 2.4	15.3	98.9 ± 1.3	13.7	66.9 ± 1.7	10.5
Fish	46.4 ± 0.7	7.3	54.0 ± 1.0	7.5	38.8 ± 0.7	7.1	31.3 ± 1.1	5.4	51.6 ± 0.9	7.8	38.9 ± 1.0	6.9
Milks	15.2 ± 0.2	3.0	14.7 ± 0.3	2.5	15.8 ± 0.2	3.6	28.6 ± 0.6	6.2	13.3 ± 0.2	2.5	10.4 ± 0.3	2.2
Oils·fats (animal)	0.1 ± 0.0	0.0	0.1 ± 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
Others (animal)	1.2 ± 0.1	0.2	1.4 ± 0.2	0.2	1.0 ± 0.1	0.2	0.5 ± 0.2	0.1	1.5 ± 0.1	0.2	0.8 ± 0.2	0.1
Beverages	5.0 ± 0.1	1.0	5.3 ± 0.1	0.9	4.8 ± 0.1	1.1	2.2 ± 0.1	0.5	6.2 ± 0.1	1.2	3.0 ± 0.1	0.6
Alcohols	2.6 ± 0.2	2.6	4.4 ± 0.3	4.4	0.8 ± 0.1	0.8	0.0 ± 0.0	0.0	3.0 ± 0.2	3.0	3.8 ± 0.4	3.8
Animal foods	229.4 ± 1.6	36.2	264.8 ± 2.3	36.7	193.9 ± 1.6	35.7	230.7 ± 3.2	41.0	247.8 ± 1.9	37.6	149.4 ± 2.3	25.7
Plant foods	361.6 ± 1.4	63.8	412.4 ± 2.0	63.3	310.7 ± 1.5	64.3	307.3 ± 2.8	59.0	371.2 ± 1.7	62.4	373.3 ± 2.5	74.3

All estimates were derived from survey-weighted analyses accounting for the complex sampling design, using integrated weights for 2018–2022.
1)Expresses the mean daily choline intake from each food group for each individual.
2)Expresses the mean of the contribution (%) of daily choline intake from each food group for each individual.

intake were grains (45.2%), eggs (13.4%), meat (12.2%), fish (7.3%), and vegetables (5.6%). By sex, the top 5 food groups were the same as those for the total population, with a slightly larger contribution from meat for males than for females. Differences in food group sources according to age were more pronounced. For children and adolescents under 18 yrs, the major food group sources were grains (45.9%), eggs (15.3%), meat (14.0%), milk (6.2%), and fish (5.4%). For older adults aged ≥ 65 yrs, the top 5 contributors to choline intake were grains (51.3%), eggs (10.5%), vegetables (7.1%), fish (6.9%), and meat (6.0%). This shows that older adults obtain much more choline from plant foods than other age groups.

We also present the choline intake contributions of the top 20 major food sources out of 571 individual foods (**Table 5**). Overall, more than 70% of daily choline intake came from the top 20 individual foods. Rice and eggs were the main sources of choline for both sexes and all age groups, with the total population obtaining just over 25% of their daily choline intake from rice and 13% from eggs. Grain-based foods contributed significantly across all sexes and age groups, with nearly half of the top 20 contributors belonging to the grain group, including rice, noodles, and bread.

DISCUSSION

The present study estimated the current status of dietary choline intake in Koreans using a newly constructed database for the choline content of foods and recent KNHANES raw data, and identified dietary sources. The mean dietary choline intake of Koreans aged ≥ 1 yr was 591 mg/day (median 544 mg/day), which corresponds to 143% of AI (median 132%). Overall,

 https://doi.org/10.4162/nrp.2026.20.3.476

Table 5. Top 20 individual foods and their cumulative contribution to daily choline intake, Korea National Health and Nutrition Examination Survey 2018–2022

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	Rice	26.3	26.3	Rice	27.4	27.4	Rice	25.1	25.1	Rice	26.3	26.3	Rice	24.3	24.3	Rice	34.9	34.9
2	Eggs	13.0	39.3	Eggs	12.4	39.8	Eggs	13.7	38.8	Eggs	14.4	40.7	Eggs	13.4	37.7	Eggs	10.3	39.3
3	Pork	4.9	44.2	Pork	5.6	45.4	Pork	4.2	43.0	Pork	5.7	46.4	Pork	5.3	43.0	Barley	3.6	44.2
4	Noodles	3.3	47.5	Noodles	3.4	48.8	Noodles	3.3	46.3	Milk	4.0	50.4	Noodles	3.6	46.6	Noodles	2.9	47.5
5	Bread	2.9	50.4	Chicken	3.1	51.9	Bread	3.2	49.5	Bread	3.5	53.9	Bread	3.0	49.6	Pork	2.3	50.4
6	Chicken	2.7	53.1	*Ramyeon*	3.0	54.9	Beef	2.5	52.0	Chicken	3.3	57.2	Chicken	3.0	52.6	Brown rice	1.9	53.1
7	Beef	2.6	55.7	Beef	2.7	57.6	Chicken	2.4	54.4	Beef	2.8	60.0	Beef	2.7	55.3	Beef	1.9	55.7
8	*Ramyeon*	2.4	58.1	Bread	2.6	60.2	Milk	2.3	56.7	*Ramyeon*	2.8	62.8	*Ramyeon*	2.7	58.0	Bread	1.7	58.1
9	Milk	2.0	60.1	Milk	1.7	61.9	*Ramyeon*	1.9	58.6	Noodles	2.8	65.6	Flour	1.7	59.7	Soybean	1.7	60.1
10	Barley	1.7	61.8	Barley	1.6	63.5	Barley	1.9	60.5	Flour	1.7	67.3	Milk	1.6	61.3	Tofu	1.7	61.8
11	Flour	1.6	63.4	Tofu	1.6	65.1	Rice cake	1.7	62.2	Rice cake	1.5	68.8	Tofu	1.6	62.9	Persimmon	1.6	63.4
12	Tofu	1.6	65.0	Flour	1.5	66.6	Flour	1.6	63.8	Tuna	1.3	70.1	Barley	1.4	64.3	Rice cake	1.4	65.0
13	Rice cake	1.4	66.4	*Kimchi*, *baechu*	1.2	67.8	Tofu	1.6	65.4	Tofu	1.2	71.3	Rice cake	1.4	65.7	Milk	1.4	66.4
14	Brown rice	1.2	67.6	Brown rice	1.1	68.9	Brown rice	1.3	66.7	Barley	1.2	72.5	Tuna	1.2	66.9	*Kimchi*, *baechu*	1.3	67.6
15	*Kimchi*, *baechu*	1.1	68.7	Tuna	1.1	70.0	Persimmon	1.0	67.7	Processed meat	1.1	73.6	*Kimchi*, *baechu*	1.2	68.1	Soybean paste	1.1	68.7
16	Tuna	1.0	69.7	Rice cake	1.1	71.1	*Kimchi*, *baechu*	1.0	68.7	Brown rice	1.1	74.7	Brown rice	1.1	69.2	Soybean milk	1.1	69.7
17	Persimmon	0.8	70.5	Sandwich/ hamburger/pizza	0.8	71.9	Tuna	0.9	69.6	Snacks	0.9	75.6	Squid	0.8	70.0	*Ramyeon*	1.1	70.5
18	Soybean	0.8	71.3	Processed meat	0.8	72.7	Soybean	0.8	70.4	Sandwich/ hamburger/pizza	0.9	76.5	Buckwheat noodles	0.8	70.8	Anchovy	1.0	71.3
19	Anchovy	0.7	72.0	Squid	0.8	73.5	Anchovy	0.7	71.1	Quail eggs	0.9	77.4	Sandwich/ hamburger/pizza	0.8	71.6	Sweet potato	0.9	72.0
20	Squid	0.7	72.7	Soybean	0.7	74.2	Sweet potato	0.7	71.8	Potato	0.8	78.2	Anchovy	0.7	72.3	Flour	0.8	72.7

All estimates were derived from survey-weighted analyses accounting for the complex sampling design, using integrated weights for 2018–2022.
[1)]Data are the mean of the contribution (%) of daily choline intake from each food for each individual.
[2)]Data are cumulative contribution (%) of daily choline intake.

https://doi.org/10.4162/nrp.2026.20.3.476

7 of 10 Koreans met the AI level for daily choline, whereas the remaining 3 did not reach the AI. Dietary choline intake below the AI was more prevalent among females and older individuals. Dietary intake above the UL was rarely observed except in a subset of children. Approximately 60% of dietary choline intake came from plant foods, with the main food sources being grains, eggs, meat, fish, and vegetables.

The findings of our study, specifically that dietary choline intake was lower in females than in males and that low intake was more profound among the elderly, are consistent with the results of previous studies conducted in other populations. However, the dietary choline intake among Koreans observed in our study differed from that in other countries worldwide. The U.S. was the first country to assess choline intake and has been estimating dietary choline intake in Americans since the mid-2000s. In the National Health and Nutrition Examination Survey (NHANES) 2007–2008, the estimated mean dietary choline intake of all individuals aged ≥ 0 yrs was 302 mg/day [37]. In 2009–2012, the estimated choline intake from both food and dietary supplements among individuals aged ≥ 2 yrs was 317 mg/day, indicating that a substantial proportion of the American population still did not meet the AI for choline [38]. In Europe, 12 national-level dietary surveys from 9 countries from 2000 to 2012 were combined with a database of choline content in foods from the USDA to estimate the choline intake of the European population [18]. In that pooled analysis, the mean daily dietary choline intake was 151–210 mg among toddlers (1 to < 3 yrs), 177–304 mg among other children (3 to < 10 yrs), 244–373 mg among adolescents (10 to < 18 yrs), 291–468 mg among adults (18 to < 65 yrs), 284–450 mg among the elderly (65 to < 75 yrs) and 269–444 mg among the very elderly (≥ 75 yrs). These findings indicate that in most European populations, the mean dietary choline intake remained below the AI set by the U.S. Institute of Medicine [1,18]. Among Asian countries, Taiwan assessed choline intake using the Nutrition and Health Survey in Taiwan 1993–1996 and the USDA database [16]. In that study, the mean dietary choline intake of the Taiwanese population aged 13–64 yrs was 325 mg/day, which did not meet the recommended values, and only a small proportion of individuals reached the recommended intake [16,20]. Recently, a narrative review analyzed the current choline intake in both European and non-European populations based on 34 studies conducted in 17 countries between 2016 and 2024 [21]. In that review, the mean daily dietary choline intake for adults was 310 mg in 9 European countries (United Kingdom, Norway, Poland, Germany, Sweden, Spain, Italy, Belgium, and Romania) and 293 mg in 8 non-European countries (U.S., Canada, Australia, Taiwan, Iran, Mexico, Palestine, and South Africa), indicating that choline intake among adults, including pregnant women, has been insufficient globally.

However, in our study, the daily dietary choline intake among Koreans was higher than that reported in other countries, with more than two-thirds of the population meeting the recommended intake. This result is in line with previous studies showing high choline intake among Koreans, including 2 studies published approximately 2 decades ago. One study analyzed the choline content of 64 and 97 food items commonly consumed by Koreans based on data from the KNHANES 1998 and 2001, respectively, and estimated the dietary choline intake of Koreans using the choline content of the foods and the per capita food intake data for the same years [23]. The mean per capita daily dietary choline intake was estimated to be 623 and 602 mg in 1998 and 2001, respectively. Consistent with the findings of our study, dietary choline intake was found to be higher in males than in females, and higher in adolescents and middle-aged adults than in other age groups. Furthermore, the overall per capita choline intake among Koreans appeared to fall within the appropriate range, with slight differences according to sex and age. Another study analyzed dietary

https://doi.org/10.4162/nrp.2026.20.3.476

choline intake directly rather than calculating it using a dietary assessment survey and food content [22]. This study employed a duplicate diet method in healthy young adults in their 20s and 30s. All foods consumed by the participants over a single day were collected, and the dietary choline content of the meals was directly analyzed using an enzymatic method. The mean daily dietary choline intake among all participants was 541 mg (median, 496 mg). The consumption of adult males exceeded that of adult females by approximately 200 mg, a finding that aligns with the observations of our study. To put these together, although some subgroups, such as adults aged ≥ 65 yrs, had low choline intake, the overall dietary choline intake among Koreans was within an appropriate range between the AI and UL.

Notable differences were observed in the main dietary sources of choline between the present study and research conducted in other populations. Choline is widely distributed in various dietary sources, with particularly high concentrations found in eggs, meat, fish, pulses, and whole grains [14,32,39]. Animal foods such as eggs and meat are the primary sources of dietary choline worldwide. For example, in the diets of Americans, the main food groups contributing to choline intake include meat, poultry, and fish; grain-based mixed dishes; dairy; and egg and egg dishes, with approximately 30% of dietary choline coming from meat, poultry, and fish, including their composite dishes [37]. The main sources of dietary choline in European populations are similar to those in the U.S., with meat, milk, grain, eggs and their derived products, composite dishes, and fish identified as the major contributing food groups [18,21]. This pattern was also observed in studies involving only female adults [17,40]. A study conducted in New Zealand reported that eggs, red meat, milk, bread, and chicken were the top 5 major sources of dietary choline in women of reproductive age [17]. In another study of Australian women during pregnancy, dairy and eggs, baked products, and vegetables were identified as the top food categories contributing to dietary choline intake [40]. However, our study found that Koreans consumed approximately 60% of their choline intake from plant-based foods, with the major choline sources being grains, eggs, meat, fish, and vegetables. Regarding individual food items, rice, eggs, pork, noodles, and bread were the main contributing foods to dietary choline intake. A substantial amount of dietary choline was derived from plant-based foods. There was little difference in the main dietary sources of choline between the sexes. However, when stratified by age group, milk contributed slightly more to choline intake among children, whereas plant-based foods, such as grains and vegetables, contributed more among older adults. These findings are consistent with those of a previous study conducted on a Korean population [23]. Such differences in choline sources likely reflect variations in the types of food commonly consumed by population groups.

The present study provides updated insights into dietary choline intake in the Korean population by merging an established choline content database with the KNHANES data. Our study has several strengths. First, this study estimated dietary choline intake among free-living Korean individuals across all age groups using nationally representative dietary survey data, highlighting the need to assess choline intake, which plays an important role in various physiological functions throughout the lifespan. Second, the accurate estimation of nutrient intake critically depends on the completeness and relevance of the food composition database [36]. In many countries where data on the choline content of locally consumed foods are lacking, researchers rely on the USDA database, which may lead to underestimation owing to unmatched food items or inaccuracies stemming from compositional differences [16,18,21,41]. In contrast, the choline content data used in our study were primarily based on values analyzed domestically, providing high coverage with minimal missing values, which significantly reduced the likelihood of underestimation of dietary choline intake among Koreans. Third, the established choline database can be used in future studies to investigate the impact of choline intake on health outcomes, thereby contributing to the generation of new evidence.

However, this study has several limitations that should be considered. First, the KNHANES dietary data were based on a single 24-h dietary recall, which limited the ability to estimate participants' usual intake and may have overestimated the proportions of insufficient and excessive choline intake in the population [42]. Second, although the choline database used in our study had high coverage and was primarily based on domestically analyzed values, nearly one-third of the choline content data were derived from the USDA database. Some inaccuracies may have occurred because variations in specific food varieties or cultivation conditions may not have been fully considered when linking choline content from the USDA to the food consumed by our population. Third, a choline content database was established using data derived from different analytical techniques, which may have affected the comparability of the values. The domestic data that we primarily relied on were analyzed using enzyme methods [32], whereas the USDA data were based on liquid chromatography/electrospray ionization-isotope dilution mass spectrometry [14]. Both methods are internationally recognized and generally produce comparable choline levels across most food groups. Discrepancies in the measured values, however, were observed only for certain foods, such as rice and wheat [32]. For rice, the staple food of our population, the choline content reported by the USDA was substantially lower than that from domestic analyses. Given that the choline content in grains varies with genotype, variety, and cultivation conditions [43], this discrepancy is likely due to the difference between the rice (long-grain species) analyzed by the USDA and the rice commonly consumed in Korea [14,32]. Although the analytical methods differed, both are internationally recognized, and we used the results from both sources to construct our database. Domestic values were prioritized, with USDA values incorporated only when domestic data were unavailable. Finally, in our study, dietary choline intake from foods alone was estimated; intake from dietary supplements and intake of specific choline forms (e.g., phosphatidylcholine and glycerophosphocholine) could not be assessed. Because different forms of choline may have distinct absorption pathways and metabolic roles in the body, future research examining the health outcomes associated with choline intake should consider the specific forms of choline consumed [26,44].

This study provides updated insights into dietary choline intake in the Korean population. Overall, the dietary choline intake among Koreans appeared to be sufficient, although intake below the AI was observed in some subpopulations. This study only estimated the dietary choline intake from foods. To gain a more comprehensive understanding of choline intake in the Korean population, further research is needed to assess the intake of both total choline and specific choline-containing compounds, as well as dietary supplements.

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