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Iodine Status of the U.S. Population, National Health and Nutrition Examination Survey, 2005–2006 and 2007–2008

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Background: This report presents urinary iodine (UI) concentrations for the general U.S. population during 2005–2006 and 2007–2008. These findings are the fourth and fifth assessments of the population since National Health and Nutrition Examination Survey (NHANES) III (1988–1994), when the median UI concentration for the population decreased from NHANES I (1971–1974).
Methods: During 2005–2006 and 2007–2008, ~5000 participants per year were selected to participate in NHANES. The participants were interviewed and examined. UI concentration was measured on a random one third subsample of 2649 participants, aged 6 years and older in 2005–2006, and in all participants in 2007–2008. These urine iodine concentrations are representative of the general U.S. population by age, sex, and race/ethnicity.
Results: (i) The median UI concentrations for the general U.S. population in 2005–2006 and 2007–2008 were 164 μg/L (95% confidence interval [CI] 154–174) and 164 μg/L (95% CI 154–173), respectively. Also, the proportions of the population with a UI concentration of <50 μg/L during these survey periods were 9.8% ± 1.3% and 8.8% ± 0.4%, respectively. The median UI concentration and prevalence of ≥200 μg/L appeared to be higher in children and persons ≥70 years than in other age groups. (ii) In both surveys, children aged 6–11 years had median UI concentrations of ≥200 μg/L, and about 5% of them had a UI concentration of <50 μg/L. (iii) All pregnant women (sample size 184) surveyed during 2005–2008 had a median UI concentration of 125 μg/L (95% CI 86–198), and 56.9% ± 7.9% of this group had a UI concentration of <150 μg/L. UI concentrations were lower among non–Hispanic black survey participants than non–Hispanic white and Mexican-American participants.
Conclusions: These findings affirm the stabilization of UI concentration and adequate iodine nutrition in the general U.S. population since 2000. However, certain groups likely do not achieve a sufficient dietary iodine intake according to the World Health Organization. The needs of these vulnerable groups and the inadequacy of their dietary iodine intake should be addressed in future efforts.

Introduction

The sufficiency of the dietary iodine intake for the general U.S. population has been monitored since 1971 through the National Health and Nutritional Survey (NHANES) (1–3). Iodine is necessary in the synthesis of thyroid hormones, which are essential for normal growth, development, and metabolism throughout life. During gestation and lactation, women have an enhanced requirement for iodine to support the development of the fetus and newborn. The most damaging effect of iodine deficiency is inadequate thyroid hormone supply to the developing brain. Thyroid hormone is particularly important for myelination of the central nervous system, which is most active during fetal and early postnatal development.

Iodized salt and seafood are the major dietary sources of iodine, although dairy and grain products are the primary sources of iodine in the American diet (4). In the United States, salt is iodized with potassium iodide, which is used by about 50%–60% of the U.S. population. However, the U.S. population receives only a small percentage of its salt from table salt because ~70% of dietary salt is derived from processed food, which uses mostly noniodized salt (5). Urinary iodine (UI) concentrations directly reflect dietary iodine intake because >90% of consumed iodized salt appears in the urine. Thus, the UI concentration is recommended for assessing a population's iodine status worldwide (6).

UI excretion is often expressed as a concentration (μg/L) or in relation to creatinine excretion (μg iodine/g creatinine). In populations with adequate general nutrition, the UI concentration correlates well with the UI/creatinine ratio. The World Health Organization (WHO) defines nutritional iodine sufficiency for a population by UI concentrations as follows: excessive iodine intake, >300 μg/L; more than adequate intake, 200–299 μg/L; adequate intake, 100–199 μg/L; mild iodine deficiency, 50–99 μg/L; moderate iodine deficiency, 20–49 μg/L;

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and severe iodine deficiency, <20 μg/L (6). WHO recently increased the recommended iodine intake for pregnant women from 200 to 250 μg/day, and suggested that a median UI concentration of 150–249 μg/L indicates dietary iodine sufficiency in this group (6). The Food and Nutrition Board of the Institute of Medicine reported age-specific recommended dietary allowances (RDA) for iodine intake for specific age groups and for pregnant and lactating women (7). For example, the RDA for iodine is 90 μg/day for children and 150 μg/day for adults. For pregnant women, the RDA increases to 220 μg/day. The daily iodine intake can be estimated from the UI concentration after making assumptions for the 24-hour urine volume and a 92% gut bioavailability for iodine (7).

The findings from the 2007–2008 NHANES, which is the largest assessment of the general U.S. population's iodine sufficiency status to date, demonstrate that the dietary intake of iodine by the population has remained at an adequate and stable level since 2000. In addition, children aged 6–11 years continue to exceed the nutritional requirement for iodine, women have a higher prevalence of dietary iodine insufficiency than men, and non–Hispanic black Americans have a lower UI concentration than non–Hispanic white and Mexican-Americans. These findings indicate that the assessment of a population's dietary iodine requirement should be comprehensive and cannot be based solely on the status of iodine sufficiency in school-aged children because vulnerable groups such as pregnant women exist within the population. A comprehensive sampling of pregnant women can provide improved estimates of the prevalence of iodine sufficiency in this country.

Subjects and Methods

Study design

NHANES is conducted by the National Center for Health Statistics at the Centers for Disease Control and Prevention (CDC). NHANES uses a stratified, multistage design to provide a representative probability sample of the civilian, noninstitutionalized population of the United States, aged 2 months and older. The surveys in this report were conducted from January 2005 to December 2006 and January 2007 to December 2008. A detailed description of sample design specifications for NHANES 2005–2006 (8) and 2007–2008 (9) has been published elsewhere. These surveys included an interview conducted at the household and an examination at a mobile examination center. The examination consisted of a variety of physical measurements and blood and urine collections. For the 2005–2006 survey, annual UI concentrations were measured in one third of ~5000 people aged 6 years and older who had been selected to represent the U.S. population for the survey. For the 2007–2008 survey, annual UI concentrations were measured in all of the ~5000 participants aged 6 years and older. Each stage of the sample selection was randomized to ensure unbiased representative estimates for the U.S. population. A detailed description of the data collection methods for NHANES has already been published (8,9) and will not be presented here.

Demographic variables

Sociodemographic data were self-reported by study participants during the interview. Information included individual characteristics such as sex, age, self-reported race and ethnicity, years of education completed, and household income information. Participants were grouped by age: children (6–11 years), adolescents (12–19 years), and adults (≥20 years). Similarly, a race/ethnicity variable was derived from self-reported questionnaire data, resulting in four categories of race/ethnicity: non–Hispanic white, non–Hispanic black, Mexican-American, and other remaining races/ethnicities.

Pregnancy variable

Pregnant women in the survey were identified in a retrospective manner. A urine pregnancy test was used to screen women aged 12–59 years to exclude pregnant participants from a dual-energy X-ray absorptiometric scan during the physical examination. Trimester information was self-reported by study participants, and this information was available for the survey years 2003–2006. Pregnant women in the 2005–2006 and the 2007–2008 surveys were represented as one group for further data analysis because of the very small sample size of these women in each survey period. Using a similar approach, a group of nonpregnant women of childbearing age (15 to <45 years) represented a comparison to the pregnant women.

Laboratory methods

During the physical examinations, spot urine specimens were collected from participants, and aliquots of these specimens were generated and stored cold (2°C–4°C) or frozen until shipped. Samples collected for UI measurement were shipped on dry ice to CDC's National Center for Environmental Health (NCEH) and were stored frozen (−70°C) for <1 year. Samples were analyzed for UI concentration using the method of Caldwell *et al.* (10). Briefly, 0.5 mL of urine was diluted 1:10 with 1% (v/v) tetramethylammonium hydroxide, 0.02% Triton X-100™, 25 μg/L tellurium (Te), 5 μg/L bismuth (Bi), 5% (v/v) ethanol, 1000 μg/L gold, and 0.5 g/L EDTA. This solution was subsequently analyzed using inductively coupled plasma dynamic reaction cell mass spectrometry as previously described (2,10). Iodine was quantified based on the peak as a ratio of analyte to internal standard tellurium. Two concentration levels of quality controls were analyzed in each analytical batch with unknown samples. Reported results met the accuracy and precision specification of the quality control/quality assurance program of the Division of Laboratory Sciences, NCEH, CDC (11). During the analysis of UI for this study, these two quality control pools were analyzed multiple times ($n = 445$), and they had a relative standard deviation of 2.79% at 93 μg/L iodine and 2.60% at 308 μg/L iodine. Absolute assay accuracy was verified by the blind analysis of two additional iodine reference solutions and the analysis of National Institute of Standard Technology (NIST) 2670A Standard Reference Material.

In healthy populations, creatinine is excreted from the body at a relatively constant rate over time, and expressing iodine results per gram of creatinine can help correct for the effect of urinary dilution. The UI concentration is presented as "per volume of urine" and "per gram of creatinine" in this report because these are the common approaches used to represent the value. Urinary creatinine concentrations were determined by using an automated colorimetric method on a Beckman

Synchron LX20 or CX3 clinical analyzer or Beckman UniCel® DxC800 Synchron (Beckman Instruments, Inc., Brea, CA) at the Collaborative Laboratory Services, L.L.C (Hartford, CT) in 2005–2006 (12) and 2007–2008 (13). Iodine concentrations were adjusted by using creatinine concentrations to correct for variable water excretion rates at the time of spot urine specimen collection.

Statistical analysis

This analysis included data from NHANES 2005–2006 and 2007–2008 for participants aged 6 years and older. Statistical analysis was conducted by using SAS, version 9.2 (SAS Institute, Inc., Cary, NC), and SUDAAN PROC DESCRIPT, version 10.0 (Research Triangle Institute, Research Triangle Park, NC), with confidence intervals (CIs) estimated based on the method of Korn and Graubard (14). In linear regression models, SUDAN PROC REGRESS was used to calculate the adjusted geometric means and their CIs. In the initial model, the main effects of urinary creatinine, sex, and racial/ethnic group were explored. Urinary creatinine was the only continuous variable considered. Separate models were considered for each age group. Adjusted geometric means were provided for all significant ($p < 0.05$) main effects. Women of childbearing age were aged 15–44 years. When sample sizes for a given subpopulation or group are small, the results must be interpreted with caution because they have large standard errors (15).

Results

UI concentration

The general U.S. population aged 6 years and older had median UI concentrations of 164 μg/L (95% CI 154–174) in 2005–2006 and 164 μg/L (95% CI 154–173) in 2007–2008, which appeared unchanged from the surveys conducted since 2000 (Table 1). Children aged 6–11 years had median UI concentrations of 239 μg/L (95% CI 193–279) in 2005–2006 and 215 μg/L (95% CI 194–240) in 2007–2008. In both survey periods, the median UI demonstrated a U-shaped distribution by age because it was higher at the age extremes than at the middle years, such as 20s–40s (Table 1). Also, non–Hispanic black participants had a lower ($p < 0.05$) UI concentration than non–Hispanic white and Mexican-American participants in all age groups after adjusting for sex and/or urinary creatinine (Supplementary Tables S1 and S2; Supplementary Data are available online at www.liebertonline.com/thy).

In the combined 2005–2006 and 2007–2008 dataset, nonpregnant women of childbearing age and pregnant women had median UI concentrations of 130 μg/L (95% CI 116–139) and 125 μg/L (95% CI 86–198), respectively (Table 2). Among pregnant women in the 2003–2004 and 2005–2006 survey periods, the median UI concentration (n = sample size) by trimester was as follows: trimester I, 182.4 μg/L (95% CI 66–423) ($n = 39$); trimester II, 154.6 μg/L (95% CI 85.5–231.3) ($n = 85$); and trimester III, 135.9 μg/L (95% CI 100–200.3) ($n = 70$) (Supplementary Table S3).

Iodine sufficiency

The prevalence of iodine insufficiency (UI <100 μg/L) in the general U.S. population was 28.2 % ± 1.1% in 2007–2008 (Table 3). The proportions of the population with UI concentrations <50 and <20 μg/L were 8.8% ± 0.4% and 1.1% ± 0.2%, respectively. Children aged 6–11 years had a prevalence of 17.0% ± 1.3% for iodine insufficiency, and 5.4% ± 1.0% of them had a UI concentration <50 μg/L. The prevalence of iodine insufficiency appears to be highest during the third, fourth, and fifth decades of life (Table 3). Similar observations were noted in the 2005–2006 survey (Supplementary Table S4).

In 2007–2008, the percent of women aged 6 years and older with a UI concentration <100 μg/L was lower in Mexican-American than in non–Hispanic black and non–Hispanic white participants (Table 3). This difference among race/ethnic groups in women was also observed at UI concentrations <50 μg/L and <20 μg/L. In male participants aged 6 years and older, the percent with a UI concentration <100 μg/L was higher in non–Hispanic black than in non–Hispanic white and Mexican-American participants (Table 3). However, this observation in male participants was not noted at lower UI concentrations.

In the combined 2005–2006 and 2007–2008 dataset, the prevalence of iodine insufficiency was 38.3% ± 1.9% in nonpregnant women of childbearing age and 56.9% ± 7.9% in pregnant women (Table 2). These estimates of prevalence corresponded to ~29.5 million nonpregnant and 1.9 million pregnant women. The percentage of nonpregnant women of childbearing age with a UI concentration of <50 μg/L was 14.8% ± 1.7%, or ~7.6 million women.

The percent of the population with a UI concentration of ≥200 μg/L or above the level for adequate requirement varied by age and race/ethnicity based on 2007–2008 data (Table 4). In non–Hispanic black and non–Hispanic white participants, children and older adults appeared to have higher prevalences of UI concentrations ≥200 μg/L than young adults. For example, 35.9% ± 4.2% of non–Hispanic black girls aged 6–11 years and 45.5% ± 9.4% women aged 70 years and older had UI concentrations ≥200 μg/L; 18.8% ± 4.1% of those aged 20–29 years had UI concentrations ≥200 μg/L. Thus, the distribution of the prevalence of UI concentration ≥200 μg/L by age in these race/ethnicities was U-shaped, which is consistent with the observation for the median UI concentration for the general population (Table 1). In Mexican-American participants, this pattern was observed in male subjects but not in female subjects. For example, 46.6% ± 4.0%, 33.4% ± 6.4%, and 33.2% ± 9.2% of Mexican-American female subjects aged 6–11 years, 20–29 years, and 70 years and older had a UI concentration of ≥200 μg/L, respectively.

Discussion

The general U.S. population in 2007–2008 was nutritionally iodine sufficient based on a median UI concentration of 164 μg/L (95% CI 154–174) and a prevalence of 8.8% ± 0.4% had a UI concentration <50 μg/L. In addition, these findings indicate that the dietary iodine intake of the general population has remained stable since 2000 because these indicators of iodine sufficiency have remained essentially unchanged in the last three U.S. surveys (2,3). However, variations in the status of dietary iodine sufficiency exist among groups in the population. For example, children aged 6–11 years are slightly above the requirement for adequate iodine nutrition (≥200 μg/L), and pregnant women are slightly iodine insufficient. Pregnant women have a median UI concentration of

Table 1. Comparison of Urinary Iodine and Iodine Corrected for Creatinine Levels by Age, Sex, Race/Ethnicity and Date of Survey, National Health and Nutrition Examination Survey (1988–94, 2001–02, 2003–2004, 2005–2006 and 2007–2008), in the United States

	1988–1994		*2001–2002*		*2003–2004*		*2005–2006*		*2007–2008*	
	Median	*95% CI*	*Median*	*95% CI*	*Median*	*95% CI*	*Median*	*95% CI*	*Median*	*95% CI*
UI (μg/L)										
Age										
6 years and above	145	140–151	168	159–178	160	146–172	164	154–174	164	154–173
6–11 years	237	220–254	249	221–292	229	184–281	239	193–279	215	194–240
12–19 years	180	171–195	205	192–215	178	144–204	194	176–224	185	164–200
20–29 years	140	135–150	156	138–175	150	118–180	147	135–162	155	144–169
30–39 years	131	123–141	152	138–183	143	121–172	117	108–140	150	135–167
40–49 years	134	116–132	142	117–172	142	122–165	134	122–153	150	128–172
50–59 years	117	111–126	141	124–172	140	111–175	176	137–203	149	132–167
60–69 years	133	121–145	154	124–179	159	131–197	172	118–209	165	145–182
70 years and above	135	130–145	197	173–225	148	109–176	224	193–254	187	170–209
Sex										
Male	160	155–167	196	180–208	178	165–193	182	172–195	176	169–186
Female	130	125–137	140	126–154	141	127–156	147	137–155	149	139–159
Race/ethnicity										
Non–Hispanic white	142	137–149	169	161–180	166	151–182	167	155–179	168	154–180
Non–Hispanic black	144	144–139	143	126–170	131	121–146	149	137–164	137	123–155
Mexican-Americans	183	177–191	187	171–206	185	164–194	188	164–210	174	162–190
Remaining ethnic groups	147	129–166	157	127–198	138	107–172	145	123–175	166	146–184
I/Cr (μg/g creatinine)										
Age										
6 years and above	127	122–133	151	142–164	142	129–154	155	142–169	157	150–166
6–11 years	251	239–270	257	224–320	246	233–270	289	231–367	273	239–303
12–19 years	127	118–135	138	130–148	118	102–132	138	117–163	134	123–147
20–29 years	97	91–103	121	106–133	114	93–128	114	92–135	115	105–124
30–39 years	108	104–113	138	118–150	104	98–117	112	96–141	137	121–152
40–49 years	113	110–119	127	104–161	135	115–154	147	113–172	141	129–153
50–59 years	129	121–141	174	139–194	139	114–156	162	127–228	161	141–183
60–69 years	143	134–155	183	159–209	179	153–215	183	153–236	189	179–204
70 years and above	169	161–179	228	186–276	180	153–238	278	245–309	244	228–261
Sex										
Male	119	115–125	145	137–160	132	121–147	147	131–159	144	137–153
Female	136	129–142	158	147–169	151	133–167	164	149–179	172	164–181
Race/ethnicity										
Non–Hispanic white	131	125–137	164	152–176	153	145–162	168	152–179	168	156–178
Non–Hispanic black	97	92–102	104	95–115	85	73–98	97	87–111	97	90–104
Mexican-Americans	157	147–167	155	142–173	147	132–163	163	153–179	167	147–186
Remaining ethnic groups	125	113–142	144	130–182	130	102–167	148	119–175	164	144–187

125 μg/L (95% CI 86–198) and a prevalence of 56.9% ± 7.9% for insufficient dietary iodine intake based on the 2005–2006 and 2007–2008 surveys. Also, non–Hispanic black Americans continue to have lower UI concentrations than non–Hispanic white and Mexican-Americans (2,3). These differences among race/ethnic groups are likely due to variations in their dietary intake (16–18). Thus, comprehensive assessments of iodine sufficiency in the general population should be continued because of differences in dietary iodine intake among groups in the population. Enhanced efforts are needed to adequately represent the nutritional iodine sufficiency of pregnant women in the U.S. population because of their small sample size in these surveys. The 2007–2008 NHANES for iodine sufficiency is the largest assessment of the general U.S. population to date, and the findings in this report support the observations from past surveys.

Children

The level of nutritional iodine among U.S. children aged 6–11 years has been above the adequate requirement level since 1998 based on WHO's epidemiologic criteria that use UI measurements (1–3,19). This status indicates that the dietary iodine intake for children in this age group is higher than the RDA, which ranges from 90 μg/(person · day) (aged 4–8 years) to 120 μg/(person · day) (aged 9–13 years) (7). This observation is consistent with the assessment conducted in 2003–2004 by the U.S. Food and Drug Administration's Total Diet Study (TDS) on the dietary intake of iodine in the population (4). Based on the TDS, the average (lower and upper bounds of the estimate) total iodine intakes for children aged 6–11 years were 255–280 μg/(person · day) and 276–304 μg/(person · day), respectively. These estimates exceeded the

TABLE 2. WOMEN OF CHILDBEARING AGE (15 YEARS TO <45 YEARS) IN THE UNITED STATES: MEDIAN AND LOW URINARY IODINE CONCENTRATIONS BY PREGNANCY STATUS BASED ON NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (2005–2008)

			<150 (μg/L)				<100 (μg/L)				<50 (μg/L)				<20 (μg/L)			
	Sample size	*Median (95% CI)*	%	*SE*	n	*Weighted* n	%	*SE*	n	*Weighted* n	%	*SE*	n	*Weighted* n	%	*SE*	n	*Weighted* n
Total	1762	133 119–141	57.5	1.7	935	31522556	38.1	1.8	603	20866039	14.6	1.7	198	8018011	1.9	0.5	26	1060063
Pregnant	184	125 86–198	56.9	7.9	95	1947122	35.3	6.6	62	1207111	11.5	3.8[a]	22	392792	5.2	4[a]	2	176756
Nonpregnant	1578	130 116–139	57.5	1.6	840	29575434	38.3	1.9	541	19658928	14.8	1.7	176	7625219	1.7	0.5	24	883307

[a]The relative standard error >30%. The NHANES guidelines recommend a relative standard error ≤30%.
SE, standard error.

daily requirements at these ages. Dairy and grain products were the major iodine sources for these children. These recent estimates of the daily iodine food intake in children are similar to those from the TDS conducted in 1991–1997 (7). In the earlier assessment, the median (standard error) values for the total daily iodine intake for children aged 4–8 years, male subjects (9–13 years), and female subjects (9–13 years) were as follows: 270 μg/(person · day) (0.01), 330 μg/(person · day) (0.01), and 270 μg/(person · day) (0.01). Thus, the findings from the TDS on the dietary intake of iodine support reports of greater than sufficient UI concentration levels in children in NHANES since 1998.

Knowledge on the long-term effects of excess iodine administration to children is limited. Children exposed to an elevated iodine concentration (462 μg/L) in drinking water in China had a higher prevalence of goiter than those exposed to drinking water with a lower concentration (54 μg/L) (65% vs. 15%) (20). Although these children were euthyroid and had an unremarkable neurologic exam, the goiter was attributed to a hypofunctioning thyroid (i.e., lower triiodothyronine, higher thyroxine [T4], and higher thyrotropin [TSH]) based on comparative thyroid function tests among these two exposure groups. An assessment of 19 counties in China demonstrated a median UI concentration >900 μg/L in the population, a mean water iodine concentration >300 μg/L, and a >10% prevalence of euthyroid goiter in these counties (21). The subacute thyroidal effects in children from the exposure to iodide are less apparent. When children were administered 80 mg of potassium iodide per day for 3 months for prophylaxis from the nuclear reactor criticality event at Chernobyl, they had an elevated TSH concentration that lasted for ~2 weeks (22).

The clinical consequence of high iodine intake is hypothyroidism or hyperthyroidism resulting from the body's inability to completely regulate the iodine load, a problem that occurs in a small percent of the population and is typically associated with an underlying thyroid disorder (22,23). Persons with an underlying autoimmune thyroid disorder appear susceptible to iodine-induced hypothyroidism. When dietary iodine intake was restricted among Japanese study participants with hypothyroidism who were taking >200 μg/(person · day) of iodine, thyroid function tests normalized in the group with negative thyroid autoantibodies (microsomal and thyroglobulin antigens) and remained abnormal in the group with positive titers (24). A slight increase in the incidence of hypothyroidism in the population was observed during a monitoring period when Denmark instituted a mandatory iodine fortification of 50 μg/(person · day) (25). The incidence rate of hypothyroidism, based on TSH and T4 concentrations, at 1 and 3 years after iodine fortification was instituted increased from baseline by a factor of 1.27 and 1.23, respectively. Persons in the population with moderate iodine deficiency who were affected most were adults aged 20–59 years. No increased incidence in hypothyroidism was observed in children and adolescents during the monitoring period.

Pregnant women

The dietary iodine sufficiency of women of childbearing age in the United States appears to have remained stable since 2001 based on the median UI concentration and the

Table 3. Percent of the Population with Low Urinary Iodine (μg/L) by Age, Sex, and Race/Ethnicity in the United States, 2007–2008 National Health and Nutrition Examination Survey

Percent of population under 20 μg/L		Age (years)									
		6 years and older	6–11 years	12–19 years	+20 years	20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70 years and older
	Sample size	7506	1109	1105	5292	801	904	870	845	911	961
Total	Percent	1.1	0.7	0.6	1.3	0.9	1.0	2.2	1.4	0.9	0.8
	SE	0.2	0.3	0.2	0.3	0.5	0.3	0.6	0.7	0.3	0.3
Male	Percent	0.70	0.2	0.5	0.8	1.0	0.5	1.1	0.70	0.70	0.9
	SE	0.1	0.1	0.4	0.2	0.6	0.3	0.7	0.5	0.4	0.8
NHW	Percent	0.7	0.0	0.6	0.8	1.3	0.4	1.0	0.6	0.8	1.0
	SE	0.2	0.0	0.6	0.2	0.9	0.3	1.0	0.6	0.6	1.0
NHB	Percent	0.9	0.5	0.0	1.2	1.7	0.0	2.0	1.2	0.0	1.4
	SE	0.4	0.5	0.0	0.6	1.2	0.0	1.6	1.2	0.0	1.4
MA	Percent	0.4	0.0	0.9	0.4	0.0	0.0	1.6	0.0	1.4	0.0
	SE	0.3	0.0	0.8	0.3	0.0	0.0	1.5	0.0	1.5	0.0
Female	Percent	1.5	1.4	0.7	1.7	0.8	1.4	3.3	2.0	1.2	0.7
	SE	0.4	0.7	0.4	0.4	0.7	0.4	0.8	1.1	0.6	0.3
NHW	Percent	1.6[a]	0.5	0.4	1.8	1.0	1.2	3.9	2.3	0.9	0.6
	SE	0.4	0.5	0.4	0.5	1.1	0.4	1.0	1.5	0.7	0.4
NHB	Percent	1.6[a]	1.4	2.5	1.5	1.0	2.0	2.0	0.0	2.8	1.2
	SE	0.3	0.9	1.6	0.3	1.0	0.3	1.3	0.0	1.5	1.1
MA	Percent	0.5	0.5	0.0	0.6	0.0	0.9	1.0	0.0	0.0	2.4
	SE	0.3	0.5	0.0	0.4	0.0	0.9	0.9	0.0	0.0	2.5

Percent of population under 50 μg/L		Age (years)									
		6 years and older	6–11 years	12–19 years	+20 years	20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70 years and older
	Sample size	7506	1109	1105	5292	801	904	870	845	911	961
Total	Percent	8.8	5.4	6.7	9.4	7.6	9.7	11.5	11.3	9.1	5.8
	SE	0.4	1.0	1.1	0.4	1.1	1.4	1.3	1.1	1.1	0.8
Male	Percent	6.1	3.0	5.1	6.7	5.3	7.7	7.3	7.5	6.6	4.5
	SE	0.5	0.7	1.4	0.5	1.1	1.5	1.7	1.8	1.3	1.7
NHW	Percent	6.0	2.1	2.9	6.9	5.2	6.4	8.3	8.6	7.0	4.6
	SE	0.6	1.0	1.4	0.7	1.5	2.0	2.5	2.1	1.6	2.0
NHB	Percent	7.2	6.9	8.0	7.0	7.5	10.8	4.9	6.1	6.2	6.2
	SE	1.0	1.9	2.0	1.2	2.7	2.6	2.1	4.2	2.9	3.5
MA	Percent	6.7	2.9	7.6	7.2	5.6	11.5	3.7	6.5	12.6	0.0
	SE	1.3	1.6	1.1	1.8	2.7	4.1	2.2	3.1	5.7	0.0
Female	Percent	11.3	8.2	8.5	12.0	9.9	11.6	15.5	15.0	11.3	6.8
	SE	0.7	1.7	1.3	0.7	2.1	2.0	1.6	1.8	2.0	1.6
NHW	Percent	11.8[a]	4.2	7.6	12.9	11.1	12.6	17.2	16.2	11.3	6.4
	SE	0.7	1.5	1.8	0.8	2.9	3.0	1.7	2.9	2.4	1.9
NHB	Percent	11.6[a]	13.1	13.9	11.0	10.0	10.8	14.9	7.6	8.7	13.3
	SE	1.4	2.9	3.0	1.4	3.6	2.4	3.1	2.6	3.7	4.3
MA	Percent	7.1	8.0	3.6	7.7	4.5	4.3	13.3	10.1	9.5	10.3
	SE	0.9	2.3	1.7	1.2	2.1	2.2	2.8	4.3	3.6	4.6

Percent of population under 100 μg/L		Age (years)									
		6 years and older	6–11 years	12–19 years	+20 years	20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70 years and older
	Sample size	7506	1109	1105	5292	801	904	870	845	911	961
Total	Percent	28.2	17.0	23.7	30.1	29.0	30.7	33.0	33.2	29.4	21.4
	SE	1.1	1.3	1.7	1.2	1.9	2.1	2.7	2.5	1.6	2.0
Male	Percent	23.7	12.5	18.4	25.9	25.1	28.2	26.4	28.5	25.2	18.3
	SE	1.3	1.7	2.3	1.4	3.1	2.2	3.2	3.3	2.4	3.3
NHW	Percent	23.1[b]	10.4	14.1	25.7	26.1	28.7	26.3	26.4	26.3	18.5
	SE	1.7	2.4	3.1	1.8	3.4	3.7	4.2	3.5	2.8	3.6
NHB	Percent	29.7	21.7	28.7	31.2	27.1	32.9	34.3	39.3	23.4	21.0
	SE	2.4	3.6	3.5	2.5	3.3	4.3	5.1	7.4	5.8	6.7
MA	Percent	21.0[b]	14.3	22.0	21.9	20.1	24.5	19.0	25.2	27.6	12.3
	SE	2.8	3.4	1.8	3.4	4.5	3.9	7.6	7.4	7.1	4.3
Female	Percent	32.6	22.1	29.6	34.0	32.9	33.2	39.2	37.7	33.2	23.8
	SE	1.2	2.0	2.1	1.4	2.8	3.3	2.9	3.4	2.0	3.5
NHW	Percent	33.1[a]	18.0	30.5	34.6	32.8	33.6	43.0	38.4	32.6	22.7
	SE	1.6	2.7	3.4	1.9	4.8	4.6	4.1	4.8	2.6	3.8
NHB	Percent	35.4[a]	30.9	34.6	36.2	35.5	41.6	36.2	30.7	37.8	33.7
	SE	2.7	3.6	4.1	2.8	4.1	5.5	4.6	4.9	5.0	6.7
MA	Percent	26.5	20.2	17.1	29.8	30.1	27.3	32.7	30.5	27.0	32.6
	SE	1.7	2.2	3.0	2.4	4.7	3.8	4.2	8.4	4.3	8.7

Low UI levels identified here are arbitrary cutoffs (<20, <50, and <100 μg/L) that are being followed by the World Health Organization.
[a] $p < 0.05$ versus MA by *t*-test. Comparison for those 6 years and older and within sex and UI categories.
[b] $p < 0.05$ versus NHB by *t*-test. Comparison for those 6 years and older and within sex and UI categories.
NHW; non–Hispanic white; NHB, non–Hispanic black; MA, Mexican-American.

Table 4. Percent of the Population with High Urinary Iodine (μg/L) by Age, Sex, and Race/Ethnicity in the United States, 2007–2008 National Health and Nutrition Examination Survey

Percent of population ≥200 μg/L			*6 years and older*	*6–11 years*	*12–19 years*	*+20 years*	*20–29 years*	*30–39 years*	*40–49 years*	*50–59 years*	*60–69 years*	*70 years and older*
Male	NHW	Sample size	1633	184	184	1265	157	200	180	191	198	339
		Percent	44.9	62.6	47.2	42.8	37.2	34.6	46.3	41.0	48.0	53.3
		SE	1.7	4.5	4.5	1.6	4.3	3.7	3.6	3.1	4.0	2.9
	NHB	Sample size	823	148	155	520	89	83	84	78	125	61
		Percent	34.7	43.0	38.8	32.4	28.6	26.8	33.1	31.8	43.5	44.4
		SE	1.7	4.5	3.7	2.9	3.6	4.7	5.9	6.3	6.5	5.1
	MA	Sample size	725	143	142	440	102	85	79	76	63	35
		Percent	45.2	56.8	50.5	42.2	34.5	46.7	44.7	39.6	46.6	62.6
		SE	2.8	3.1	2.7	3.6	6.4	7.1	3.2	7.3	7.4	6.7
Female	NHW	Sample size	1514	143	155	1216	139	191	217	173	187	309
		Percent	37.5	55.1	45.6	35.2	35.7	34.7	31.4	33.3	34.3	43.7
		SE	1.9	4.1	3.6	2.1	4.7	3.0	5.1	4.5	3.8	4.3
	NHB	Sample size	851	146	146	559	92	96	96	89	111	75
		Percent	30.7	35.9	32.9	29.7	18.8	23.1	33.3	36.9	32.9	45.5
		SE	2.8	4.2	3.5	3.2	4.1	5.0	3.8	6.1	4.4	9.4
	MA	Sample size	757	152	122	483	93	106	76	80	88	40
		Percent	39.1	46.6	45.6	36.1	33.4	40.6	31.6	40.2	35.1	33.2
		SE	2.6	4.0	3.8	2.7	6.4	4.1	3.2	8.7	6.0	9.2

High UI level identified here is an arbitrary cutoff (≥200 μg/L) that is being followed by the World Health Organization.

prevalence of iodine insufficiency reported in NHANES for this group (2,3). For women of childbearing age, the median UI concentration remains at ~130 μg/L and the prevalence of a UI concentration <50 μg/L remains at about 15%. However, these estimates for pregnant women have been more variable than those for nonpregnant women of childbearing age over the years. For example, the median UI concentration for pregnant women ranged from 125 μg/L (95% CI 86–198) in 2005–2008 to 181 μg/L (95% CI 100–219) in 2001–2002, and the prevalence of a UI concentration <100 μg/L ranged from 20.8% ± 5.6% in 2003–2004 to 35.3% ± 6.6% in 2005–2008 (2,3). The variability in these estimates of the central tendency and prevalence likely reflects sample bias because NHANES was not designed to represent pregnant women statistically in the survey. As seen in the CIs, some potential factors contributing to the wide variation in the UI concentration among pregnant women include race/ethnicity and gestational trimester. Despite these concerns regarding the survey design, a portion of pregnant women in the United States remains iodine insufficient based on WHO's criterion of a UI concentration <150 μg/L (19). In the combined dataset for 2005–2006 and 2007–2008 NHANES, 56.9% ± 7.9% of pregnant women had a UI concentration <150 μg/L; however, this number is based on a sampling of only 184 women. The assessment of 100 pregnant women from Boston, Massachusetts demonstrated that 49% of them had a UI < 150μg/L (26). A larger sampling of pregnant women that is representative by race/ethnicity can provide a more stable estimate of the iodine sufficiency for this group in the general population than the current survey. Also, this information can strengthen the recommendation to pregnant women for iodine supplementation during pregnancy to maintain sufficient iodine stores in the body (27).

The health risk to the fetus from maternal iodine insufficiency is greatest during the first trimester because the fetus is reliant upon maternal iodine stores for thyroid hormone synthesis. A maternal median UI concentration ≤50 μg/L during the first half of gestation can cause thyroid abnormalities such as increased thyroid gland size and elevated TSH and thyroglobulin concentrations in the newborn (28,29). Also, a maternal UI concentration >50 μg/L during the second trimester, an increased thyroglobulin, and a decreased free T4 index can cause thyroid abnormalities in the newborn (30,31). Iodine supplementation during pregnancy can ameliorate these effects in the newborn (28,29). Also, iodine supplementation can decrease the prevalence of postpartum goiter from iodine deficiency caused by gestation and lactation (32,33). The Food and Nutrition Board of the Institute of Medicine recommends an iodine intake of 220 μg/(person · day) for pregnant women (7). This dose approximates a UI concentration of 150 μg/L. In 2006, the American Thyroid Association recommended that pregnant women take an iodine supplement of 150 μg/day because the lower limit of the 95% CI for the median UI concentration estimate for pregnant women in the 2003–2004 NHANES was below the recommended value (27). The findings in this report support this decision and the need for an improved assessment of the iodine sufficiency of pregnant women in the United States.

Nonpregnant women of childbearing age with low iodine sufficiency can also benefit from iodine supplementation because some of them may not be aware that they are in the early stages of pregnancy—a time when iodine sufficiency is extremely important. During 2005–2008 NHANES, an estimated 29.5 million women in this category had UI concentrations below the WHO recommendation for iodine sufficiency. Among these women, an estimated 76.2 million had UI concentrations <50 μg/L. Also, iodine supplementation before pregnancy compared with iodine supplementation during pregnancy appears to decrease a woman's risk for abnormal thyroid function tests (i.e., decreased free T4 and increased TSH) (34). Thus, the likelihood for thyroid abnormalities among newborns can be reduced by preventing the

occurrence of maternal thyroid abnormalities due to iodine insufficiency (27–29).

The relation between UI concentration and thyroid function in American pregnant women was studied using NHANES III data (35). These pregnant women had a median UI concentration of 140.5 μg/L (95% CI 124.3–180.2) and a prevalence of 6.9% $\pm$ 1.9% for a UI concentration <50 μg/L. Also, the prevalence for TSH >4.5 mL/UI was 1.3% $\pm$ 1.1% in these women. In this cross-sectional study, no significant relation was found between UI concentration, TSH, and T4 (35). A low UI concentration in these women was not associated with hypothyroidism as defined by serum TSH and T4 concentrations. These observations are consistent with those from other studies (36,37) and suggest that pregnant women in the United States are mildly iodine insufficient. However, an improved survey design for pregnant women is recommended to confirm these findings.

The 2007–2008 survey is the largest sampling of the U.S. population to assess nutritional iodine sufficiency by using UI concentration. The significance of this large survey is the ability to characterize vulnerable groups in the population who may be difficult to evaluate because of their small sample size. This factor contributes to an improved assessment of the overall population for a country. WHO has historically based a country's nutritional iodine status on the UI concentration from school-aged children and used such data to estimate global iodine sufficiency. In the 2007–2008 NHANES, children aged 6–11 years have more than adequate levels of iodine in their diets as demonstrated by their median UI concentration of 215 μg/L and the small prevalence of 3.9% for a UI concentration <50 μg/L. If the country's iodine status was based only on this information, the iodine status of pregnant women would not be recognized. The median UI concentration of pregnant women in 2005–2008 was 125 μg/L, and 56.9% of them had a UI concentration <150 μg/L. These data indicate that pregnant women in the United States appear to be at a slight risk for iodine insufficiency; however, a representative sampling of pregnant women is needed to confirm the implication. Further, a national survey on school-aged children cannot be used to represent a country's nutritional iodine status because other vulnerable groups in the population likely have a different nutritional iodine status. Thus, a comprehensive assessment of the population is necessary to characterize the nutritional iodine status of a country properly.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

Disclosure Statement

The authors declare that no competing financial interests exist.

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