0021-972X/98/$03.00/0
Journal of Clinical Endocrinology and Metabolism

Vol. 83, No. 10
Printed in U.S.A.

Iodine Nutrition in the United States. Trends and Public Health Implications: Iodine Excretion Data from National Health and Nutrition Examination Surveys I and III (1971–1974 and 1988–1994)

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ABSTRACT

Iodine deficiency in a population causes increased prevalence of goiter and, more importantly, may increase the risk for intellectual deficiency in that population. The National Health and Nutrition Examination Surveys [NHANES I (1971–1974) and (NHANES III (1988–1994)] measured urinary iodine (UI) concentrations. UI concentrations are an indicator of the adequacy of iodine intake for a population. The median UI concentrations in iodine-sufficient populations should be greater than 10 μg/dL, and no more than 20% of the population should have UI concentrations less than 5 μg/dL. Median UI concentrations from both NHANES I and NHANES III indicate adequate iodine intake for the overall U.S. population, but the median concentration decreased more than 50% between 1971–1974 (32.0 ± 0.6 μg/dL) and 1988–1994 (14.5 ± 0.3 μg/dL). Low UI concentrations (<5 μg/dL) were found in 11.7% of the 1988–1994 population, a 4.5-fold increase over the proportion in the 1971–1974 population. The percentage of people excreting low concentrations of iodine (UI, <5 μg/dL) increased in all age groups. In pregnant women, 6.7%, and in women of child-bearing age, 14.9% had UI concentrations below 5 μg/dL. The findings in 1988–1994, although not indicative of iodine deficiency in the overall U.S. population, define a trend that must be monitored. (*J Clin Endocrinol Metab* **83:** 3401–3408, 1998)

IODINE deficiency is the world's leading cause of intellectual deficiency. Although cretinism, hearing loss, goiter, and severe neurological damage are usually associated with severe iodine deficiency, mild to moderate intellectual impairment exceeds the more severe outcomes in total numbers, significance for the community, and social impact on a population. The importance of iodine deficiency was addressed by the Rome Conference on Nutrition and by national leaders attending the 1990 World Summit for Children, which called for the virtual elimination of iodine deficiency by the year 2000 (1). Iodine deficiency leads to impaired production of T_4 and T_3, hormones that are essential for pre- and postnatal brain development and that require iodine for their synthesis. The greatest impact of iodine deficiency on cognitive and neurological function occurs during gestation and early infancy (2). The population risk for iodine deficiency has been defined and can be assessed on the basis of many measures, including urinary iodine (UI) concentration. Iodine intake and excretion are in a steady state with renal excretion, approximating the amount of iodine ingested and absorbed (3). According to the WHO, the median UI concentration in iodine-sufficient populations should be greater than 10 μg/dL, and no more than 20% of the population should have UI concentrations below 5 μg/dL (4). A UI concentration adjusted for creatinine concentration (I/Cr) of less than 50 μg iodine/g creatinine also indicates possible iodine deficiency (5).

This study complements previous qualitative dietary intake studies (6–8) by analyzing the concentration of UI in the population of the United States from data collected by the National Health and Nutrition Examination Surveys (NHANES). We have now compared data from NHANES III (1988–1994) with those from NHANES I (1971–1974), paying particular attention to the groups excreting UI concentrations less than 5.0 μg/dL. This report identifies trends in iodine nutrition and provides a basis for ensuring, or planning for, iodine adequacy in the United States in the 21st century.

Received March 23, 1998. Revision received June 23, 1998. Accepted July 1, 1998.

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* Research Fellow of the Oakridge Institute for Science and Education through a cooperative agreement among the National Center for Environmental Health and the U.S. Department of Energy (D.M.D.), the Centers for Disease Control (R.J.J.), and the National Center for Environmental Health.

TABLE 1. Characteristics of the populations with urinary iodine measured in 1971–1974 (NHANES I) and 1988–1994 (NHANES III) in the U.S., ages 6–74 yr

	Sample		Population		Males (%)	Females (%)
	n	%	n	%		
NHANES I						
Total	16,660	100.0	165,668,522	100.0	48.5	51.5
Races						
White	13,330	80.0	145,751,022	88.0	42.9	45.1
Black	3146	18.9	18,314,910	11.1	5.1	6.0
Remaining	184	1.1	1,602,590	1.0	0.5	0.4
Ethnic groups	Information not collected in NHANES I					
Regions	Regions not analyzed in NHANES I					
Age (yr)						
6–11	1,826	11.0	20,989,991	12.7	6.6	6.1
12–19	2,473	14.8	29,847,231	18.0	9.1	8.9
20–29	3,090	18.5	30,322,965	18.3	8.9	9.4
30–39	2,232	13.4	21,683,307	13.1	6.1	7.0
40–49	1,856	11.1	22,011,828	13.3	6.5	6.8
50–59	1,414	8.5	20,878,290	12.6	6.1	6.5
60–69	2,466	14.8	15,225,663	9.2	4.0	5.2
70–74	1,303	7.8	4,709,247	2.8	1.2	1.6
NHANES III						
Total	20,369	100.0	209,272,161	100.0	49.2	50.8
Races						
White	12,986	63.8	172,999,481	82.7	41.0	41.7
Black	6,635	32.6	26,487,886	12.7	5.9	6.8
Remaining	748	3.7	9,784,794	4.7	2.4	2.3
Ethnic groups						
White non-Hispanic	6,825	33.5	153,240,102	73.2	36.3	36.9
Black non-Hispanic	6,378	31.3	25,447,545	12.2	5.6	6.5
Mexican Americans	6,278	30.8	12,740,227	6.1	3.2	2.9
Remaining ethnic groups	888	4.4	17,844,287	8.5	4.1	4.4
Regions						
Northeast	2,608	12.8	42,548,714	20.3	10.1	10.3
Midwest	3,781	18.6	49,050,108	23.4	11.6	11.8
South (including Texas)	8,791	43.2	72,305,836	34.6	16.9	17.7
West	5,189	25.5	45,367,503	21.7	10.6	11.1
Age (yr)						
6–11	3,058	15.0	20,838,056	10.0	5.2	4.7
12–19	3,066	15.1	26,988,580	12.9	6.6	6.3
20–29	3,412	16.8	38,181,760	18.2	9.0	9.2
30–39	3,244	15.9	41,392,394	19.8	9.7	10.1
40–49	2,528	12.4	32,678,397	15.6	7.6	8.0
50–59	1,810	8.9	21,668,069	10.4	5.0	5.3
60–69	2,236	11.0	19,593,728	9.4	4.3	5.1
70–74	1,015	5.0	7,931,176	3.8	1.7	2.1

Subjects and Methods

The NHANES surveys were designed to give national normative estimates of the health and nutritional status of the U.S. civilian, noninstitutionalized population. NHANES I, conducted from 1971–1974, was a survey of U.S. residents of the coterminous United States, aged 1–74 yr, excluding people residing on Indian reservations. A sample of approximately 32,000 people was studied (9). NHANES III was conducted from 1988–1994. A sample of the population 2 months or older was selected, 33,994 individuals (86%) were interviewed, and 30,818 were examined. This survey represented, but did not include, all 50 states and the District of Columbia. The general structure of the sample design for the two studies is the same: a stratified, multistage probability design. Biological samples were collected from participants for a large number of biochemical indicators of health status. The detailed demography and sampling scheme was described previously (10, 11). Among those samples were urine samples collected at the time survey participants visited the mobile examination center. Ten-milliliter aliquots of urine were prepared, frozen (−20 C), and shipped on dry ice to the analytical laboratories for testing (12). Both surveys contained information on UI and creatinine concentrations in individuals 6 yr and older. Spot urine samples were collected from fasting participants because collection of 24-h urine samples was not feasible for survey purposes. Urinary creatinine was also measured to correct for urinary dilution that could affect the concentration of iodine. Examinees aged 12 yr and older were instructed to fast for 10–16 h before the morning examination or for 6 h before the afternoon or evening examination. The duration of the fast was recorded (12).

For both surveys information was collected on income levels, metropolitan/nonmetropolitan residency, and race, categorized as white, black, and remaining races. In NHANES III, ethnicity was added and included white non-Hispanic, black non-Hispanic, Mexican-American, and remaining ethnic groups. The regions identified in NHANES III were northeast, midwest, south (including Texas), and west. Because the regions identified in NHANES I contained different states than those in NHANES III, we did not analyze NHANES I data for regional differences or compare regional data between the surveys.

Laboratory methods

Iodine. In both NHANES I and NHANES III, UI concentrations were determined using the Sandell-Koltoff reaction as modified by Benotti *et al.* (13, 14). UI concentrations in NHANES I were determined by the NHANES Laboratory, Centers for Disease Control (CDC; Atlanta, GA), on samples from 18,617 people. (13) In NHANES III, UI concentrations were determined by the Iodine Research Laboratory, University of Massachusetts Medical Center (Worcester, MA), on samples from 22,070

people. The UI detection limit for the method used by both laboratories was 0.2 μg/dL. In NHANES I, iodine standards were prepared from analytical grade potassium iodide (KI), consisted of 10 levels of KI covering the range of 0.1–1.0 μg/mL, and were analyzed in duplicate with every 80–120 urine samples. In NHANES III, iodine standards were prepared from analytical grade potassium iodate (KIO_3), consisted of 4 levels of KIO_3 covering the range 0.0–0.3 μg/mL iodine, and were analyzed in duplicate with every 10 urine samples. Calibration procedures were similar for both laboratories. UI concentrations are calculated from the slope and *y*-intercept of the standard curve. A quality control sample was digested and analyzed with every 10 urine samples. Samples were repeated for values below 0.1 μg/mL by using a larger sample size and for those above the highest standard by diluting the sample. The coefficient of variance for UI determination ranged from 3.8–11.0% in NHANES I and from 2.7–7.0% for NHANES III.

Creatinine. Urinary creatinine in both surveys was measured by the Jaffé alkaline picrate method, so that iodine concentration adjusted for creatinine concentration (I/Cr) could be calculated. Concentrations of creatinine standards of 50, 100, 150, 200, 250, and 300 mg/dL were analyzed in duplicate with every 60 urine samples. Urinary creatinine concentrations were calculated from the slope and *y*-intercept of the standard curve. Quality control samples were analyzed with every 20 urine samples. Repeat limits were below 10 and above 300 mg/dL. The creatinine detection limit for this method was 1 mg/dL. The coefficient of variance for urinary creatinine determination ranged from 2.9–4.7% in NHANES I and from 1.5–7.7% for NHANES III (12, 13).

Statistical analyses

We analyzed data with SUDAAN to account for the complex sample survey design using sample weights. When we compared regions and race in NHANES III, we standardized for age and sex using the distribution of the entire population. When we studied changes between the surveys, we standardized for age and sex in accordance with the population of NHANES III. To study characteristics of subjects with UI concentrations below 5.0 μg/dL, we calculated prevalences, prevalence differences, and prevalence ratios. In accord with WHO recommendations, we compared medians and proportions excreting UI concentrations below 5 μg/dL or I/Cr concentrations below 50 μg/g because the data were severely skewed to high values, perhaps due to exposure to iodine-rich substances such as medications or x-ray contrast agents.

Results

The characteristics of the study population and of the population represented by the individuals providing UI samples in NHANES I and NHANES III, shown in Table 1, indicate a larger overall sample and less extensive oversampling of females in NHANES III compared to NHANES I. Non-Hispanic blacks, Mexican-Americans, and children were over sampled in NHANES III. The age distributions were otherwise similar.

Recent patterns (1988–1994)

In 1988–1994, the median UI concentrations for the entire population was 14.5 μg/dL. The average concentrations of UI and I/Cr in younger people were greater than those in older people. As shown in Table 2, males had higher median UI concentrations than females (16.0 *vs.* 13.0 μg/dL; <0.00001). UI concentrations also varied by race, poverty level, and region of the country (Table 3). The difference in iodine concentration between residents of metropolitan areas and residents of nonmetropolitan areas was small and lacked statistical significance ($P = 0.32$). Of the entire population, 11.7% had UI concentrations less than 5.0 μg/dL (Fig. 1).

In the 1988–1994 survey, the percentage of people with UI concentrations less than 5.0 μg/dL was greater among those above the poverty level than among those below ($P = 0.00016$), greater among whites than blacks ($P < 0.00001$), and greater among people in the northeast ($P = 0.04$) and midwest ($P = 0.01$) than among those in the south.

TABLE 2. UI and I/Cr concentrations in 1971–74 (NHANES I) and in 1988–94 (NHANES III), in the U.S., by age and gender

	UI (μg/dL)				I/Cr (μg/g)			
	1971–1974		1988–1994		1971–1974		1988–1994	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Total	45.2	32.0	26.5	14.5	463.3	293.3	254.5	124.6
(6–74 yr)	(1.2)[a]	(0.6)	(2.8)	(0.3)	(25.5)	(3.9)	(23.8)	(2.5)
Male	49.1	35.3	29.4	16.0	414.0	274.8	237.6	117.9
	(1.9)	(0.6)	(4.9)	(0.3)	(22.9)	(4.2)	(44.1)	(2.5)
Female	41.5	28.5	23.7	13.0	510.3	314.7	270.8	133.2
	(1.4)	(0.7)	(3.3)	(0.3)	(44.0)	(5.1)	(30.7)	(3.2)
6–11 yr	55.6	42.1	30.5	23.7	619.3	467.3	339.6	251.3
	(3.6)	(1.1)	(1.9)	(0.9)	(46.0)	(13.3)	(26.5)	(7.6)
12–19 yr	52.2	40.9	46.2	18.0	371.9	305.0	350.8	126.9
	(2.6)	(1.4)	(21.5)	(0.6)	(14.6)	(5.5)	(177.6)	(4.3)
20–29 yr	42.0	33.7	19.3	14.0	382.1	259.9	137.4	96.6
	(1.2)	(1.0)	(0.9)	(0.4)	(54.5)	(6.2)	(5.1)	(3.2)
30–39 yr	37.2	29.4	24.3	13.1	343.1	258.5	166.8	108.3
	(0.9)	(1.3)	(7.1)	(0.5)	(15.8)	(6.6)	(24.5)	(2.2)
40–49 yr	39.9	29.1	18.9	12.3	438.5	292.9	253.6	113.2
	(1.8)	(0.9)	(1.3)	(0.4)	(36.2)	(6.2)	(76.0)	(2.3)
50–59 yr	48.2	27.6	25.8	11.7	678.3	299.5	270.1	129.4
	(6.7)	(1.2)	(5.9)	(0.4)	(196.6)	(8.5)	(50.0)	(4.8)
60–69 yr	43.5	26.3	25.6	13.3	449.3	289.3	397.3	143.2
	(3.5)	(0.9)	(2.4)	(0.6)	(30.4)	(6.8)	(68.6)	(5.2)
70–74 yr	58.9	26.9	26.9	12.9	735.9	303.1	316.4	157.4
	(10.9)	(1.1)	(5.5)	(0.4)	(197.5)	(8.7)	(64.0)	(4.6)

All values were adjusted for age and/or gender and nonresponse.
[a] The SE for means and medians was calculated using SUDAAN is in *parentheses.*

TABLE 3. Median UI and I/Cr concentrations and percentage of individuals with UI concentrations below 5 μg/dL or I/Cr concentrations below 50 μg/g, by gender, race, economic status, population density, region, and survey, in the U.S.: NHANES I and NHANES III

	UI (μg/dL)				I/Cr (μg/g creatinine)			
	1971–1974		1988–1994		1971–1974		1988–1994	
	Median	% <5	Median	% <5	Median	% <50	Median	% <50
Total population	32.0	2.6	14.5	11.7	293.9	0.7	124.6	7.5
	(0.6)[a]	(0.2)	(0.3)	(0.5)	(3.9)	(0.1)	(2.5)	(0.5)
Males	35.3	1.6	16.0	8.1	274.8	0.7	117.9	9.0
	(0.6)	(0.3)	(0.3)	(0.6)	(4.2)	(0.2)	(2.5)	(0.6)
Females	28.5	3.5	13.0	15.1	314.7	0.7	133.2	6.1
	(0.7)	(0.3)	(0.3)	(0.7)	(5.1)	(0.1)	(3.2)	(0.6)
Race								
White	32.2	2.6	14.7	12.2	301.8	0.6	129.6	6.3
	(0.7)	(0.3)	(0.3)	(0.6)	(4.2)	(0.1)	(2.9)	(0.5)
Black	31.1	1.8	14.5	8.1	231.8	1.5	97.1	15.2
	(0.8)	(0.4)	(0.3)	(0.5)	(5.7)	(0.4)	(2.3)	(1.0)
Remaining races (other)	27.2	5.9	13.3	11.3	251.6	0.2	120.8	8.5
	(2.4)	(3.9)	(1.2)	(2.0)	(30.6)	(0.2)	(9.3)	(1.4)
Ethnicity								
White Non-Hispanic			14.2	13.0			127.6	6.4
			(0.3)	(0.6)			(2.9)	(0.6)
Black Non-Hispanic			14.4	8.2			96.3	15.5
			(0.3)	(0.6)			(2.3)	(1.0)
Mexican American			18.3	6.7			155.8	3.9
			(0.3)	(0.4)			(5.0)	(0.5)
Remaining groups (other)			14.7	9.3			124.1	7.7
			(0.9)	(1.5)			(7.0)	(0.8)
Economic status								
Poverty	29.9	3.5	15.9	9.0	289.6	1.0	132.7	8.6
	(1.3)	(0.6)	(0.5)	(0.7)	(7.9)	(0.3)	(4.3)	(0.7)
Above poverty	32.3	2.5	14.2	12.1	294.1	0.6	123.7	7.3
	(0.6)	(0.3)	(0.3)	(0.6)	(3.9)	(0.1)	(2.5)	(0.5)
Unknown poverty	33.6	1.9	14.9	10.8	293.0	0.8	123.0	7.9
	(1.8)	(0.6)	(0.7)	(2.1)	(10.1)	(0.4)	(7.5)	(1.4)
Regions								
Northeast			13.4	12.2			118.5	9.7
			(0.9)	(0.8)			(5.5)	(0.7)
Midwest			13.4	12.8			111.7	9.4
			(0.3)	(0.5)			(3.1)	(0.7)
South (including Texas)			15.4	9.9			135.1	5.6
			(0.3)	(0.7)			(4.5)	(0.5)
West			15.3	12.7			134.6	6.4
			(1.0)	(1.7)			(7.5)	(2.1)
Population density								
Urban	31.8	2.3	13.9	11.6	290.2	0.8	120.1	8.1
	(0.6)	(0.3)	(0.3)	(0.7)	(4.9)	(0.1)	(2.6)	(0.5)
Nonurban	32.6	3.2	15.0	11.7	300.3	0.5	129.2	6.9
	(1.6)	(0.4)	(0.5)	(0.8)	(6.1)	(0.1)	(4.7)	(1.0)

All values were adjusted for age and gender.
[a] The SE for medians and proportions calculated using SUDAAN is in *parentheses*.

Time trends

As shown in Fig. 1, UI concentrations for the U.S. population were, overall, substantially lower in 1988–1994 than in 1971–1974. The median UI concentration fell from 32.0 μg/dL in 1971–1974 to 14.5 μg/dL in 1988–1994 ($P < 0.0001$). When categorized by participants' race, metropolitan/nonmetropolitan residence, poverty status, or region of the country, the median UI concentrations in 1988–1994 were about half those found in 1971–1974 (Table 3). The proportion of the population with UI concentrations below 5.0 μg/dL was 4.5 times higher in 1988–1994 than in 1971–1974, ($P < 0.0001$). This increase in the proportion of people with low levels was seen for all demographic categories (Table 3) and for all age groups (Fig. 2). In 1988–1994, 8.1% of males and 15.1% of females had UI concentrations below 5 μg/dL. As shown in Fig. 2, the highest prevalence of low concentrations was in the 40- to 49-yr-old age group (23.1% of women and 12.7% of men). Among white non-Hispanics, the percentage with UI concentrations below 5.0 μg/dL was even higher in women of this age group (25.5%).

The percentage of women of child-bearing years (15–44 yr) with UI concentrations below 5 μg/dL increased 3.8 times between the two study periods, and the percentage of pregnant women with UI concentrations below 5.0 μg/dL increased 6.9 times (Table 4).

In estimating excessive iodine intake, 27.8% of the 1971–1974 population exceeded the UI concentration of 50 μg/dL, and 5.3% exceeded 100 μg/dL. In 1988–1994, 5.3% of the population exceeded UI concentrations of 50 μg/dL, and 1.3% exceeded 100 μg/dL.

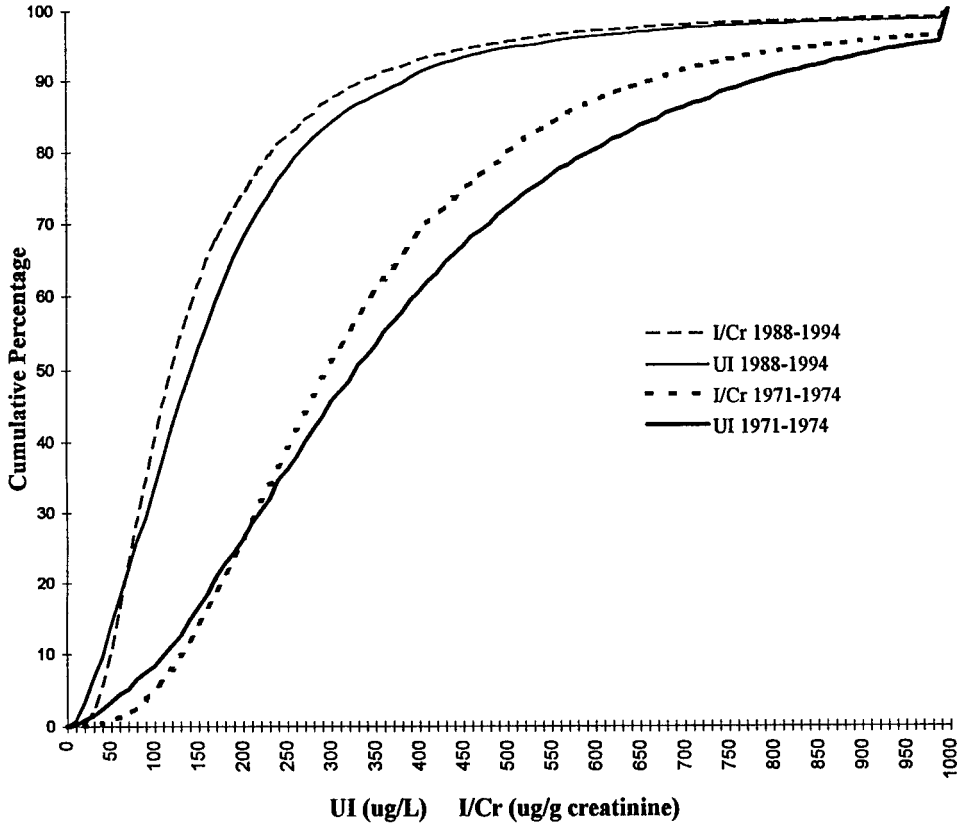

FIG. 1. Comparison of UI concentrations, NHANES I and NHANES III. The population in 1971–1974 had greater UI concentrations than in 1988–1994. Note the numbers of individuals in both time periods with very high concentrations of iodine. To display UI and I/Cr together in this figure, UI is expressed as micrograms per L in this figure instead of micrograms per dL as seen in the text and tables.

When adjusted for creatinine concentration, the median I/Cr ratio in NHANES III (124.6 μg/g creatinine) was lower ($P < 0.0001$) than that in NHANES I (293.3 μg/g creatinine). The total population with I/Cr concentrations below 50 μg/g had increased 10-fold. The number of women of child-bearing age with I/Cr concentrations below 50 μg/g had increased 9-fold, and the percentage of pregnant women with these low levels had also increased. When comparing the I/Cr ratios, adult men, aged 20–64 yr, had lower values than women of those ages. Male children excreted higher concentrations of iodine in urine than female children for both I/Cr and UI concentrations (Fig. 3).

We compared UI excretion patterns in the first 3 yr (1988–1991) with those in the last 3 yr (1991–1994) of NHANES III to determine whether a trend in UI concentrations could be detected within the 6 yr of the 1988–1994 survey. The median UI concentrations and the proportions of individuals with UI below 5 μg/dL from 1988–1991 were not significantly different from those between 1991–1994 ($P > 0.8$).

Discussion

The authors of the Total Diet Studies (6), which are conducted yearly by the U.S. FDA to provide estimates of the intakes of nutrients by selected age-sex groups as well as the quality of the food supply for the U.S. population, concluded that the iodine intake for the U.S. population is adequate (7, 8). The median UI concentration in both NHANES studies exceeded the WHO definition as adequate for a population (4) and thus has provided quantitative support of the Total Diet Study. Even though there is overall adequate iodine intake in the U.S. population, the sizable decrease in UI concentrations between the two NHANES study periods (1971–1974 and 1988–1994) and the relatively large percentage of individuals with UI concentrations below 5 μg/dL found in the 1988–1994 study are grounds for some concern.

The increased proportion of women of child-bearing age and pregnant women who are in the iodine deficiency range is particularly important because iodine deficiency in fetuses and infants can lead to irreversible intellectual deficits with great impact on populations (15). Although the overall median intake of iodine in the United States is within acceptable limits, particular groups, namely women aged 40–49 and 50–59 yr and other women of child-bearing age, may be at risk for iodine deficiency. In Belgium, Glinoer *et al.* reported that the addition of 100 μg iodine daily to the diet of pregnant women significantly decreased maternal TSH and thyroglobulin concentrations and thyroid volume. In the newborn, serum thyroglobulin concentrations and thyroid volume also decreased (16). Such findings emphasize the importance of adequate iodine nutrition.

Although the laboratory analyses for iodine were conducted in different laboratories 14–20 yr apart, the methods used were identical. Analytic grade potassium iodide in 1971–1974 and analytic grade potassium iodate in 1988–1994 were used to prepare standard iodine concentrations, and quality assurance and controls for both laboratories and time periods were considered entirely satisfactory by the NHANES study groups. Reassuringly, in another study, May *et al.* (17) showed close agreement among six different methods used in six laboratories for the iodine range studied,

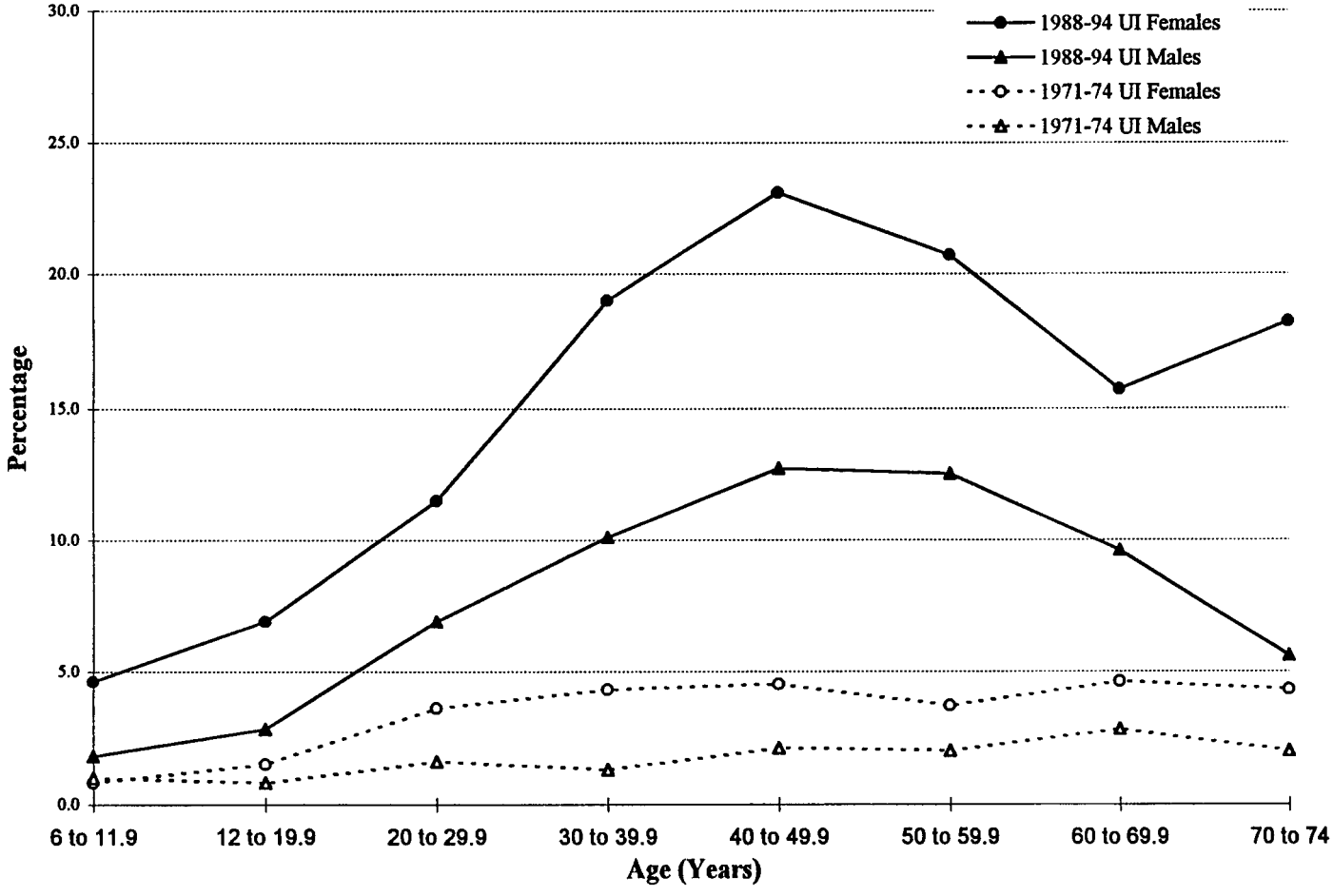

FIG. 2. Percentage of the population with low UI concentration. The percentage with low concentrations of iodine is greater in 1988–1994 than in 1971–1974. The prevalence of low iodine values was highest among people 40–60 yr old.

TABLE 4. Median concentrations of UI in women of child-bearing age (15–44 yr) in 1971–1974 and in 1988–1994, and percentage who had UI concentrations below 5 μg/dL or I/Cr concentrations below 50 μg/g creatinine in the U.S. by known pregnancy status

	NHANES I, 1971–1974					NHANES III, 1988–1994				
	UI			I/Cr		UI			I/Cr	
	No.[a]	Median	% <5	Median	% <50	No.[a]	Median	% <5	Median	% <50
Total	5279	29.4 (1.0)[b]	3.9 (0.5)	287.3 (6.3)	0.9 (0.1)	5405	12.8 (0.4)	14.9 (1.1)	113.1 (3.2)	8.2 (0.9)
Known pregnant	208	32.7 (3.5)	1.0 (0.6)	373.0 (20.8)	0.1 (0.1)	348	14.1 (1.4)	6.9 (1.9)	132.2 (11.9)	5.1 (1.9)
Not pregnant	5071	29.3 (1.0)	4.0 (0.5)	284.1 (6.3)	0.9 (0.1)	5057	12.7 (0.4)	15.3 (1.2)	111.9 (3.2)	8.4 (0.9)

[a] Number of women in sample.
[b] The SE for medians and proportions calculated using SUDAAN is in *parentheses.*

with no method showing a bias or inconsistency serious enough to alter the public health interpretation of their dataset, and showed a high correlation (≥0.9), indicating good intermethod comparison for individual samples. Thus, we found no supportive data that the use of different laboratories or the time between studies explains the differences in observed UI concentrations.

Daily iodine intake is most closely estimated by the amount of iodine excreted in the urine in 24 h. To compensate for the lack of a 24-h urine collection, in populations with adequate nutrition, the creatinine concentration has been used to adjust for factors that may affect the concentrations of the substances being measured during the collection period. Although used widely, the I/Cr ratio adds little and may be misleading with regard to iodine excretion in developing countries where nutrition is poor, thereby affecting creatinine excretion (18). The usefulness of the I/Cr ratio in the United States for population iodine studies has been questioned. Thomson *et al.* compared UI results from spot samples with those from 24-h collections samples from 62 adults and determined that "... fasting urine samples, but not casual urines, may give a reasonable estimate of urinary

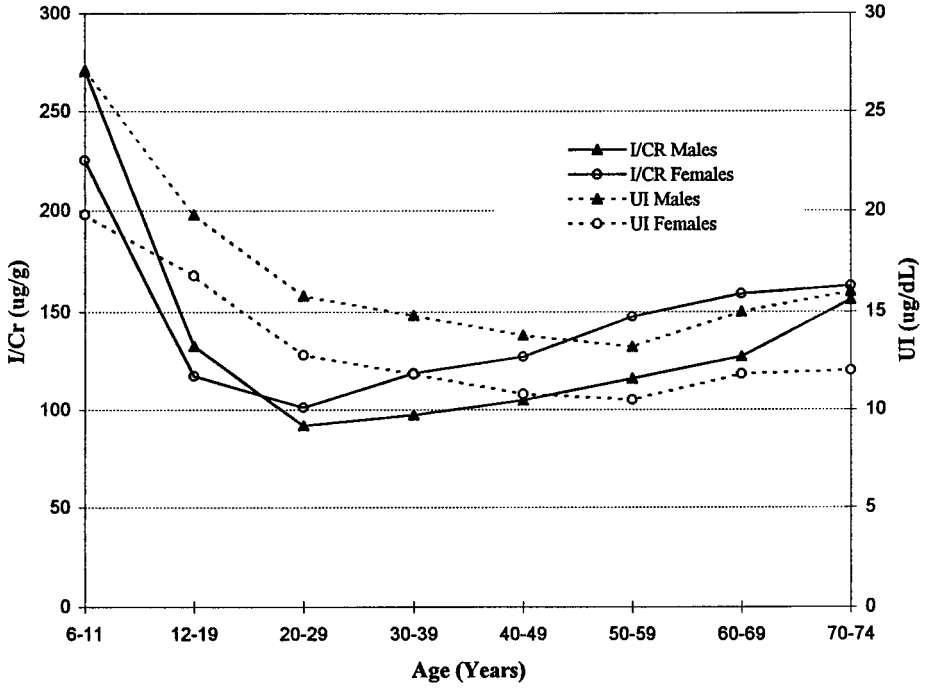

FIG. 3. Adjustment of UI concentration. Overall median values of UI are higher in males than in females of all ages. Among children, I/Cr concentrations are higher in males, but in adults, I/Cr concentrations are higher in females.

output of iodine . . . on a population basis. . . . " (19). In both NHANES studies, urine was collected after a period of fasting, and similar protocols were used; thus, the urine collection procedures used should not have contributed to the differences observed.

We included I/Cr data in our analyses, primarily for comparison with the results from previous Canadian and US studies. The 1971–1974 (NHANES I) values were similar to the findings of the Canadian national study of 1969–1972 (20), which reported that less than 1% of the population had I/Cr concentrations below 50 μg/g. In the Canadian study, no pregnant women and less than 0.2% of women of childbearing age had I/Cr concentrations below 50 μg/g. Metropolitan, urban, and rural populations did not differ in I/Cr concentration. Most individuals of both sexes had I/Cr concentrations between 100–550 μg/g. Slightly lower values were found in males 20–39 yr old and males over 60 yr of age (20). In the U.S., Trowbridge *et al.* in a 1972 study of 7,785 children aged 9 to 16 yr (21) and in the Ten-State Nutrition Survey from 1968–1970 of 16,799 subjects aged 2 yr and older (22) found I/Cr values to be in the range of those found during the same approximate time period in NHANES I.

In Switzerland (23), where iodine prophylaxis has been practiced for a number of years and iodine intake is thought to be adequate, studies showed evidence of iodine deficiency and prompted health officials to increase the iodine content of salt; to reestablish health education programs focusing on the use of sea products, milk, and iodized salt; and to improve the monitoring programs for iodized salt (24). Iodine deficiency was also found in other continental European countries (25). Iodine deficiency, which was severe in some locations, may have contributed to the increased incidence of thyroid cancer among children exposed to fallout of ^{131}I from the Chernobyl, Ukraine nuclear disaster in 1986, as thyroid radioactive iodine uptake is increased in areas of iodine deficiency (26).

In the United States iodized salt was introduced to prevent goiters in the upper Midwest in 1922. As the voluntary use of iodized salt spread rapidly throughout the country (27, 28) and as iodine was added to processed foods and milk products (29), the prevalence of goiter declined (30). Within 50 yr the country had excessive iodine intake to the extent that other forms of thyroid problems, namely iodine-induced hypothyroidism, autoimmune thyroiditis, and hyperthyroidism, had become of more concern than deficiency disorders (31). The 1982–1991 surveys from Total Diet Study may explain the decrease in UI concentration. The authors of that study argue that the apparent decline in iodine intake from 1982–1991 did not represent a trend, but was probably due to higher iodine intake during 1982–1984 than during the remaining 7 yr (8). The decrease since 1984 was thought to be due to the dairy industry's effort to reduce iodine in milk and to the replacement of iodine by bromine salts as the dough conditioner in commercial bread production (7).

We need to know whether the decrease in UI concentrations seen between 1971–1974 and 1988–1994 can be explained entirely by the 1982–1984 changes seen in food production or whether additional factors or trends not measured by the Total Diet Study are involved, such as the use of iodized table salt or prepared "fast foods." Although the total consumption of iodized salt remains at about 50–60% of all salt consumed (Hanneman, R. L., Salt Institute, Alexandria, VA; personal communication), the extent to which voluntary reduction in added salt use by segments of the population concerned about sodium intake and hypertension has contributed to lower UI concentrations is unknown.

In 1971–1974, 27.8% of the population had excessive UI concentrations (>50 μg/dL), and the decline of those with

excessive UI to 5.3% in 1988–1994 may be seen as beneficial in possibly reducing diseases due to iodine excess such as Hashimoto's thyroiditis and perhaps Graves' disease (31). Should the intake of iodine continue to decrease in the United States, in addition to a further change in the pattern of thyroid diseases, a portion of the population could become iodine deficient, resulting in the following consequences: 1) a reduction in the intellectual capacity of children born to mothers receiving insufficient amounts of iodine while pregnant, and 2) a rise in the prevalence of simple iodine deficiency goiter and nodular goiter. Whether the reduced UI seen in 1988–1994 can be directly correlated to measurable changes in thyroid function in the population is not known at this time because the results of thyroid function tests and thyroid antibodies in the 1988–1994 study are not available as yet, and comparison with results in 1971–1974 is not possible because TSH and antibodies were not measured in NHANES I. We know of no population-based study in the United States, such as transient neonatal hypothyroidism or recent goiter surveys, that have shown changes that resulted from decreased iodine intake. It will be important to know what UI concentrations in a population will predict thyroid dysfunction.

Clearly, the iodine intake in the United States has decreased over the past 20 yr. Awareness of a possible continuing decline in iodine intake in this population can be achieved by monitoring the food supply, especially the intake of iodine in women of child-bearing age. This monitoring can be performed by continuing the measurement of iodine in the Total Diet Study and by including UI in the next NHANES survey, which is about to begin. Surveillance of thyroid diseases should be emphasized, but we should not wait for the prevalence of goiter to increase or for changes in thyroid disease patterns to occur due to decreased iodine intake. Should surveillance indicate a further decrease in iodine intake, measures may be required to increase the amount of iodine consumed by the U.S. population to prevent the possibility of the reemergence of iodine deficiency in the United States.

Acknowledgments

The authors recognize and thank Dr. Samuel P. Caudill, National Center for Environmental Health, CDC, for reviewing and assisting in validating the analytic processes. We thank the professionals who developed and conducted the HANES surveys as well as those generating data used for this study. We are grateful to Richard Hanneman, Salt Institute (Alexandria, VA), for information on salt use and the iodine content of salt. We appreciate the thoughtful comments of Dr. Kevin Sullivan, Rollins School of Public Health, Emory University; Dr. Barbara Bowman, Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, CDC; Dr. Scott Grosse, National Center for Environmental Health, CDC; Dr. Geraldine McQuillan, the National Center for Health Statistics, CDC; and Dr. Elizabeth Yetley, FDA.

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