This article is published in Journal of Nutrition 1/11/2025.

Iodine intake trends in US girls and women between 2011 and 2020

Abstract word counts: 292, Text word counts: 4453, 4 tables and 2 figures.

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Disclosure statement: The authors declare that there is no conflict of interest regarding the publication of this paper. There is no external funding source for the project. The results were not presented at any conferences and were not made public in any manner.

Abbreviation Explanation

ATA: American Thyroid Association

CDC: US Centers for Diseases Control and Prevention

EAR: Estimated Average Requirement

FDA: US Food and Drug Administration

FNDDS: Food and Nutrient Database for Dietary Studies

FPED: Food Patterns Equivalents Database

HEI: Healthy Eating Index

MEC: US CDC Mobile Examination Center

NCHS: US National Center for Health Statistics

NCI: US National Cancer Institute

NHANES: US National Health and Nutrition Examination Survey

ODS-NIH: Office of Dietary Supplements, US National Institute of Health

UIC: urinary iodine concentration

USDA: US Department of Agriculture

WHO: World health organization

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ABSTRACT

Background: Usual intakes of iodine in US girls and women, including pregnant and lactating women have not been adequately studied. Adequate intake of iodine is critical for neurodevelopment of girls, thyroid functions and reproductive health of women.

Objectives: This study aimed to examine the adequacy and trends of iodine intake of US girls and women between 2011 and 2020.

Methods: We mapped sources of US girls and women's iodine intake from the 29 food groups between 2011 and 2020 using US Department of Agriculture's iodine data release 2. The total food intakes from two days of dietary recall of the US National Health and Nutritional Examination Survey and estimated iodine concentrations of the food groups were used to calculate the usual iodine intakes of female participants. Trends of usual intakes, urinary iodine concentrations (UIC) and estimated intake adequacy were calculated.

Results: Median usual intakes of iodine estimated from diet and supplements and UIC of US girls and non-pregnant, non-lactating women declined between 2011 and 2020 in all three age groups: 14 years and younger, 15-49 years old and 50 years and older. Median usual intakes of iodine for pregnant and lactating US women declined as well. Inadequacy levels of usual iodine intake were 9.9% for non-pregnant, non-lactating women of reproductive age 15-49 years old, 40.3% for lactating and 10.2% for pregnant women in 2017-2020 period. Intake insufficiencies estimated from UIC were 48.8%, 63.2% and 31.3% for non-pregnant-nonlactating women of reproductive age 15-49 years old, pregnant and lactating women respectively in 2017-2020 period. A significant decline in milk consumption might be one of the major contributors to the dietary iodine decline in US women.

Conclusions: Iodine intake of US girls and women were on the decline between 2011 and 2020 and the increased inadequacy of iodine intake deserves public health attention.

Key words: iodine intake trend of US girls and women; iodine deficiency; dietary iodine intake; urinary iodine concentration; iodine adequacy of US pregnant and lactating women

INTRODUCTION

Iodine is an essential micronutrient and an integral component of thyroid hormones that regulate many important biochemical reactions of girls and women, including those who are pregnant and lactating (1-4). Iodine deficiency has been linked to impairment in neurodevelopment and adverse academic performance in school aged children (5). Iodine deficiency during pregnancy can result in offspring neurodevelopmental deficits and, in extreme cases, in cretinism (6). For lactating women, iodine is needed in breast milk to provide the growing baby with the iodine necessary for healthy development of the brain and nervous system (2,7). Iodine related subclinical and overt hypothyroidism in adult women, outside pregnancy can also result in a range of adverse metabolic, neuropsychiatric and cardiovascular outcomes (5,8). Excessive iodine intake can cause hyperthyroidism, hypothyroidism and thyroid autoimmunity (9).

Two previous studies of iodine intake (10,11) established the basic levels of mean and median iodine intakes of US population for 2008-2012 and 2003-2010 sample years. The 1st study reported the mean iodine intake from diet excluding water and salt (10). The second study reported the estimated mean and median of dietary iodine including the iodine from diet, water and salt and the iodine intake estimation from urinary iodine concentration (UIC) (11). A significant difference between the iodine intake estimated from diet and from UIC existed in the latter study (11). Estimations of usual iodine intakes of pregnant and lactating US women were lacking. Results from National Health and Nutrition Examination Survey (NHANES) I and III showed an approximately 50% decline of UIC between the early 1970s and the early 1990s for US population (12). Two recent examinations of UIC between 1999 and 2020 also reported a decline of UIC in the US population (13,14). It is likely that the current usual iodine intake of US girls and women had further declined from that of previous years given the continued decline in milk consumption (15), a major source of iodine. An update of trends in iodine intake is needed based on the most recent iodine composition data of food items (16) and the available dietary interview data, particularly for pregnant and lactating US women.

The aim of this study was to assess the recent usual intake of US girls and women, including pregnant and lactating women, between 2011 and 2020 using the Release 2.0 of the US Department of Agriculture, Food and Drug Administration, Office of Dietary Supplements-US National Institute of Health (USDA, FDA and ODS-NIH) Database for the Iodine Content of Common Foods (16). The reason that period of 2011 through 2020 was selected was because the 24-hr iodine supplemental data from NHANES were only available beginning with 2011-2012 cycle and the most recent data were from the 2017-2020 sample cycle. A secondary aim was to identify the food sources that may have contributed to the sustained decline of iodine intake in US girls and women.

MATERIALS AND METHODS

Demographic Data

Data of 21753 female participants aged 2 years and older with dietary data between 2011-2020 NHANES sample cycles were extracted (17). Age, sex, race, interview and subsample weights were obtained from demographic and corresponding sample files in NHANES database. The demographic data were part of the interview questions administered during the Mobile Examination Center (MEC) interview. Female participants aged 14 and under were categorized as girls, female participants 15-49 years old were categorized as women of reproductive ages and female participants 50 years and old were categorized as a third group. All female participants who answered “yes” to the question “Now breastfeeding a child?” in the Reproductive Health data file were classified as breast-feeding or lactating women and those who had positive test result for the “pregnancy status at Exam” were classified as pregnant women in this study. Female participants who were not pregnant nor breast-feeding and 15 years and older were classified as non-pregnant, non-lactating women. Girls 14 years and younger, women 15-49 years old and 50 years and older were 26.6%, 40.9% and 32.4% of the participants analyzed in this study respectively (Table 1).

NHANES is a nationally representative cross-sectional study conducted by the National Center for Health Statistics (NCHS) of US Centers for Diseases Control and Prevention (US CDC). It collects information on health and nutritional status of the non-institutionalized civilian population in the US (18). The study design, protocol, and data collection methods have been reported extensively elsewhere. More detailed information on the design and methods of NHANES is available on the NHANES website (18). The NHANES study protocol was approved by the research ethics review board of the NCHS of US CDC, and all participants provided written informed consent (19). Because NHANES data are deidentified, ethical approval for the analyses of the data in the current study was not needed.

Dietary Interview Data

NHANES nutritional assessment from the 24-hr dietary recall interview includes nutrients and non-nutrient components from foods and beverages that were consumed during the 24-hr period prior to the interview (midnight to midnight). Food Patterns Equivalents Database (FPED) across survey cycles 2011–2020 were used with Individual Foods of Dietary Interview of day 1 and day 2 data to assess the 37 MyPyramid food groups of each participants. Details on the component definitions can be found on the USDA FPED's document files online (20). FPED divides the foods and beverages in the Food and Nutrient Database for Dietary Studies (FNDDS) of NHANES into the 37 USDA Food Patterns components. The total equivalent food intakes of day 1 and day 2 files for each responding sample person and each record have data on the number of equivalents of each of the 37 MyPyramid food groups. These are also the food groups that are typically used for calculating the Healthy Eating Index (HEI) of 2015 calculation used in the National Cancer Institute method (21,22). Among the 37 food groups, 29 are individual food groups and 8 are category groups. Category group is classified here as the group for which its total iodine intake content can be summarized from the corresponding individual food groups. For example, iodine intake of dairy category group for a participant will be the summary iodine intake from milk, cheese and yogurt individual food groups. The NHANES's four-year sample cycle for 2017-2020, instead of the traditional 2-year cycle was because of Covid-19 interruption in the field operation in 2020. The incomplete 2019-2020 data were combined into 2017-2018 to create the national representative data of 2017-2020 (17).

Because water and salt intakes also contributed to the iodine intake for NHANES participants, iodine intake from water and salt intakes of each participant were estimated following prior practices (11,14). Therefore, a total of 31 groups (29 individual food groups, water and salt) were used to estimate the iodine intake of each participant. For the usual intake analyses of iodine, the dietary and supplement intakes of qualified participants from two 24-hr dietary recalls (day 1 and day 2) were used in this study.

UIC Data

US CDC measured UIC in spot samples from approximately one-third of the 2011−2020 participants aged 3 years and older. Spot urine samples were collected from the selected participants at the time of the MEC examination when the day1 dietary interview data were gathered, and the procedures for collecting, storing, and handling specimens are described in detail on the NHANES website. The UIC was determined by using inductively coupled plasma mass spectrometry by the Elemental Analysis Laboratory of the CDCs Division of Laboratory Science (23,24). Because 90% of absorbed iodine is ultimately excreted in the urine, UIC can reflect individual's most recent iodine intake. UIC data will be used as a method to estimate the population's insufficiency levels of iodine intake following the guideline given by World Health Organization (WHO) (25). 7890 female NHANES participants with urinary iodine data between 2011-2020 were included in this study.

Estimation of Iodine Concentrations

Iodine from foods

Iodine Content of Common Foods releases 2 from USDA, FDA and ODS-NIH has 425 food items with iodine concentrations in mcg/100 grams (26). Their iodine concentration data were measured by FDA and USDA labs using inductively coupled plasma mass spectrometry (26,27). Because 425 food items in the database are far fewer than 6200+ food items in FNDDS, multiple foods of FNDDS were mapped together to obtain the iodine concentrations of the 29 FPED food groups. They were mapped with the consideration of proportion of the items taken in the dietary items and the mean concentration of respective food category in the database. The final mapped iodine concentration used for the 29 food items and their equivalent weight per cup or ounce are given in Appendix Table A1. Total dietary iodine intake from food items of the participants was the summary product of equivalent weight per cup or per ounce (Table A1), iodine concentration in mcg/100 grams and the amount of food intake of each of the 29 groups of a participant. We estimated iodine concentrations of 29 individual FPED groups, drinking water, and salt used in cooking and the table. Total iodine intake of each participant is the summary of iodine intakes from food, water, salt and supplement.

Iodine from drinking water and salt

Following Juan et al. (11), using an iodine concentration of 9.2 µg/L, median value measured at various US locations in available studies (27,28), iodine intake from water was calculated as the product of the intake volume of plain water and 9.2 ug/L.

A recent study reported that 53% of the salt sold in the US was iodized salt when weighted by sales volume in ounces or per item (29). About 11% of sodium intake was from salt (30,31). Salt contains 387.6 mg sodium per gram (11). It is generally accepted that salt used in industrial food processing does not contain iodine. For iodized salt, the iodine concentration is 45 µg/g (32). The iodine intake per 100 grams of sodium is therefore calculated as 100g*0.11/0.3876g/g*0.53*45 ug/g=677.9 ug or 677.9 mcg per 100 grams of sodium intake.

Estimation of Iodine Intake Sufficiency from UIC

Estimation of iodine intake sufficiency from urinary concentration was based on WHO's criteria (25). For girls and non-pregnant women, a UIC level below 100 ug/L was considered iodine insufficient, 50-99 µg/L was considered mildly deficient, 49-20 ug/l was considered moderately deficient, below 20 ug/L was considered severely deficient and above 300 ug/l was considered excessive for this group. For lactating women, UIC below 100 ug/L was considered insufficient. For pregnant women, UIC below 150 ug/L was considered insufficient and above ≥500 µg/L was considered excessive in this study.

Outcomes

The main outcomes were the median and trends of usual intake of iodine and UIC of three age groups of NHANES female participants: girls 14 years and younger, women of reproductive ages 15-49 years old and women 50 years and older between 2011 and 2020. They also include the median usual intakes and UIC of lactating and pregnant US women. Median usual intakes of five racial groups: Mexican American (Mexican A), Non-Mexican Hispanic Americans (NM Hispanic), non-Hispanic white (White), non-Hispanic black (Black or African A), and other races (Other) of non-pregnant, nonlactating US women were also presented. The second level outcomes were the percentages of inadequacy below Estimated Average Requirement (EAR), percentages above the Upper Limit and trends of iodine intake based on dietary and supplement intake, the percentages of estimated iodine intake insufficiency based on UIC and iodine supplement intake. Percentage of the median iodine intake below the EAR was defined as the proportion of the population at risk of iodine inadequacy. Percentage of population with above the upper limit of iodine intake was defined as having excessive iodine intake. The third level outcomes were the percentages of iodine contributions from the 11 main food categories and groups: total fruit, total vegetable, whole grain, refined grain, total mps (total meat, poultry and seafood), eggs, milk, yogurt, cheese, water and salt and their trends.

Statistical Methods

The US National Cancer Institute (NCI) method (33) was used to estimate usual intake of iodine based on the day 1 and the day 2 iodine intake data calculated from the summary of their 29 food groups, water and salt. The first step of NCI method modeled the probability of consuming a given nutrient and the amount for nutrients that are consumed daily by most persons. The second step involved estimating usual intake with parameters estimated from the first step using mixed effect linear regression on a transformed scale with a person-specific effect. Mean and median usual intakes and inadequacy proportion of iodine using the NCI method (33), and percent of food components, their 95% confidence intervals (CI) and standard errors (SE) were calculated in SAS (SAS Institute Inc., version 9.4).

Statistical analyses including weighted means, medians and 95% CI of UIC data of non-pregnant, nonlactating participants were calculated in Stata (version 17, StataCorp LLC) using its Survey Data Analysis (34). For pregnant and lactating women, the regular descriptive stats method in Stata instead of Survey Data Analyses was used for analyses because of the small sample size (Table 1). A five-point linear regression model was used to calculate significance levels of trend (p-trend) of iodine intake with the modeled population medians or means of five sample cycles as dependent variable, and years 2012,2014,2016,2018 and 2020 as independent variable. Significance level was set at 0.05 (95% CI). The percentage changes of the median or means were calculated as the differences of the medians or mean of population in 2017–2020 and 2011–2012 over the medians or means in 2011-2012.

RESULTS

Iodine intakes from diet and supplements and intake insufficiency estimated from UIC

The median total usual iodine intake (diet+ supplements) declined from 224.3±4.7 to 196.4 ±3.8, from 184.1±5.2 to 164.8±2.7, from 202±7.7 to 188.9±6.2 mcg/24 hrs between 2011-2012 and 2017-2020 for three ages groups of US girls 14 years and younger, non-pregnant, nonlactating women 15-49 years old and 50 years and older (Table 2). These median levels were above the EAR 95 mcg/24 hrs for women aged 14 years and older (35) (for the EARs of other age groups, see note under Table 2). The median iodine intake of pregnant women ranged from 186.8±18.7 to 215.7±27.1 mcg/24 hrs between 2011-2012 and 2017-2020, were well above the EAR 160 mcg/24 hrs during the five sample cycles. For lactating women, their median usual intake ranged from 259.6±21.6 to 219.1±35.1 mcg/24hrs between 2011-2012 and 2017-2020 and were above the recommended EAR of 209 mcg/24 hrs as well. The median usual iodine intakes of women estimated from diet and supplement were lower in African American women than other racial groups (Figure 1a). The median UICs of girls aged 14 years and younger were higher than that of other age groups (Figure 1b).

Iodine intake inadequacies for non-pregnant, nonlactating women of reproductive age between 2011-2012 and 2017-2020 based on diet and supplement ranged from 0.5% to 1.1%, 4.5% to 9.9% and 4.9% to 15.9% for girls 14 years and younger, women 15-49 years old and 50 years and older respectively. The intake inadequacies for pregnant and lactating women ranged from 5.6% to 23.7% and 0 to 44.8% respectively. Intake insufficiency based on UIC ranged from 27.1% to 36.5%, 46.5% to 50.7%, 36.5% to 45.2% for the three ages groups respectively, from 52.9% to 63.2% for pregnant women and from 17.7% to 74% for lactating women between 2011-2012 and 2017-2020 sample years. Excessive intakes based on UIC were higher in girls aged 14 years and younger (16.7% to 23.1%) than in women aged 15-49 years old (9.5% to 14.1%) and 50 years and older (14.6% to 18.9%).

The percentages of pregnant and lactating women who took iodine supplements were significantly higher than that of non-pregnant and non-lactating US women of reproductive ages 15-49 years old (42.9±5.7%, 29.6±6.2% vs.13.4±1.1%) in 2017-2020 sample years based on day 1 interview data (Figure 2a). White Americans had the highest percentage of taking iodine supplements among all races during this period (Figure 2b).

Trends of iodine usual intake, UIC and iodine supplement

Median usual intakes of iodine from diet alone declined significantly in the 5 sample-cycle years (2011-2020) for girls 14 years and younger, non-pregnant, nonlactating women of 15-49 years old and 50 years and older and lactating women. For iodine intake from total dietary and supplement, the median usual intake declined significantly for girls 14 years and younger and non-pregnant, nonlactating women of 15-49 years during this period (Table 2). The percentages of inadequacy increased and excessive intake declined during this period for all three age groups. Trends of median usual intakes of pregnant and lactating US women declined, but not significantly.

Median UIC for girls 14 years and younger and non-pregnant, nonlactating women of aged 15-49 years old and 50 years and older declined between 2011 and 2020. Percentages of total insufficiency estimated from UIC based on WHO criteria all increased for all three age groups and for pregnant women between 2011 and 2020 (Table 3). The decreasing percentage of moderate deficiency for women of reproductive age (15-49 yrs) was significant. The median UICs for pregnant and lactating US women increased between 2011 and 2020 (Table 3).

Overall, the percentage taking iodine supplements rose for women aged 15 years and older, but declined for girls aged 15 years and younger (Figure 2a) between 2011 and 2020.

Contribution of food groups to total dietary iodine intake

The largest iodine intake food category for US women was the dairy products which accounted for 49.3± 0.8% of the total iodine intake in US girls and women in 2011-2012 (Table 4). This share of contribution from dairy food to iodine intake dropped to 43.6±0.67 % in 2017-2020 and that is a decline of 11.6±2% (Table 4). Though there were increases in the iodine intake from cheese consumption (rose from 7.5% to 8 %) and yogurt (rose from 4.1% to 4.3%), the percentage share of iodine intake from milk declined from 37.7% to 31.3% between 2010-2012 and 2017-2020 sample cycles (Table 4). The corresponding median (±SE) UICs of four quartiles of dairy intakes, from the lowest to the highest dairy consumption quartiles, are 170.5±10.8, 196.9±17.1, 208.9±23.6 and 344.6±80 ng/mL respectively. This shows an apparent association between higher UIC level and increased dairy consumption.

The second largest food category for iodine intake was the refined grain with 18.8% to 20% between 2011-2012 and 2017-2020. Its share increased from 2011 to 2020, but not significantly. The proportional contribution to iodine intake increased from 3% to 4.4 % for eggs and from 10.5% to 11.8% for added salt between 2011 and 2020 sample cycles (Table 4). Dietary iodine contribution from total meat, poultry and seafood ranged from 5.1% to 6.6%, rose slightly. Dietary iodine contribution from total meat, poultry and seafood ranged from 5.1% to 6.6%, rose slightly. Most contributions in the group of meat, poultry and seafood were from seafood, at 4±0.4%, 5.1±0.6%, 4.6±0.4%,4.8±0.5%, 4.6±0.4% for the five sample cycles respectively, between 2011 and 2020. Consumption of seafood in both low and high n-3 fatty acids decreased, but not significantly (regression slope t=-0.83, significance level p=0.469 and t=-0.01, p=0.991 respectively).

Among the three-age groups, milk contribution to the total iodine intake was 48.6% for girls 15 years and younger, 28.6% for women of reproductive age, 15-49 yrs old and 31.4% for women aged 50 years and older. Contribution of iodine intake from refined grain and salt intakes were higher for women of reproductive age group than for other age groups.

DISCUSSION

Comparing trends and values of iodine intake with that of prior studies

Median usual intakes of dietary iodine and UICs of US girls and non-pregnant, non-lactating women declined between 2011 and 2020. These trends are consistent with the iodine intake trends reported in two recent studies based on UIC alone between 2001 and 2020 for the general US population (13,14). They followed the declining UIC trend observed between 1970s and 1990s (12). The proportion of US women 15 years and older who took iodine supplements increased during this period and this is consistent with the increased intake of overall supplements in the general US population (36,37). The increased iodine supplement intake likely contributed to the rising trends of UICs in pregnant and lactating women between 2011 and 2020 (Figure 2 and Table 3). However, dietary iodine intake (excluding supplement) for lactating women still declined significantly during the period of 2011 to 2020 (Table 2).

Comparing to the mean iodine intakes of varied age groups reported by Abt et al. (10) based on diet data of 2008-2012, the median usual intakes in current study are similar to theirs in 2011-2016, but slightly lower than theirs in more recent years 2017-2020. We added the total iodine intake from salt and water while Abt et al. (10) did not. Iodine intakes reported by Juan et al. (11), for the 2003-2010 women population, were higher than ours. The differences between our study and these two prior studies (10,11) may be attributable to three factors. The first factor is the significant decline of milk consumption in recent years that represents an important source of iodine. The second factor is the iodine intake estimation from salt in which we assumed 53% of salt used being iodized (28) instead of previous estimates of 70% (11,32). The third likely factor is the iodine concentration mapping strategy for categorized food groups. However, these two studies did not report the trend of the iodine intake of women for the period they studied. Similar to that of Juan (11), we found differences between iodine intake inadequacy estimated from diet and supplement using EAR and insufficiency estimated from UIC. We think the different criteria (EARs and UIC criteria) used in the estimation of iodine adequacy from diet and supplement and from UIC largely contributed to this difference. In addition, the possible inaccuracy in dietary iodine estimation from food items and iodized salt might have contributed to this as well. UIC is considered a good marker of population's iodine intake by WHO (25).

Median usual intakes of non-pregnant, non-lactating African American women 15 years and older estimated from diet and supplement was the lowest among all races except that of Non-Mexican Hispanic women (Figure 1), yet median UICs of African American women was higher than that of Mexican American women and other races. This difference might be related to the higher sea food consumption among African American women than other racial groups (38,39) while NHANES day 1 and day 2 survey might not have captured the infrequent sea food consumption (with high iodine concentration) of women (11).

This study is likely the first study, to our best knowledge, that trends and iodine usual intakes of US women, particularly pregnant and lactating women, between 2011 and 2020 were analyzed. The results can have policy importance for the developmental, reproductive and other related health for US girls and women.

Declining iodine intake and the milk contribution

Milk has about 35 mcg/100 grams of iodine, compared to that of vegetables, beef, chicken and regular enriched white bread at averages of about 0.61, 8.23, 1.65 and 1.5 mcg/100 grams of iodine respectively (16,40). Milk iodine contribution declined from 37.7% to 31.3%, a 6.4% reduction between 2011 and 2020. It has long been recognized that the percentage of US women consuming milk declined (15). Though there were increases in the iodine intake from cheese, yogurt, eggs and added salt, their increase did not negate the decreased percentage of iodine intake from milk. The positive association of UIC with intake of dairy consumption was apparent in this study. Our result is consistent with the result of a prior study that people with more frequent consumption of milk products tend to have higher UIC than those with rare or never consumption of milk products (14). Decreased levels of iodine in milk due to the reduced use of iodine-containing feed supplements and iodophor sanitizing agents in the dairy industry were also suggested as reasons for iodine intake decline (41). Reduced use of iodate dough conditioners by commercial bakers was suggested as one of the contributors to the iodine decline as well (42).

Clinical Implications

Iodine intake estimated from diet-supplement and UIC for US women of reproductive aged 15-49 years old were the lowest among the three age groups. Iodine intake insufficiency estimated from UIC between 2011 and 2020 were approaching the 50% mark for this group of US women and surpassed 50% for pregnant women.

WHO recommends 250 mcg iodine supplement per day for women during pregnancy and breast-feeding, otherwise 120 mcg per day (24). The American Thyroid Association (ATA) recommends that women take a dietary supplement containing 150 mcg/day of iodine three months prior to conception and while pregnant and lactating to support fetal growth and neurological development (43). Only 42.9% (SE±5.6%) pregnant, 29.6% (SE±6.2%) breast-feeding and 13.4% (SE±1.1%) non-pregnant, nonlactating women of reproductive ages 15-49 years old took any iodine supplement during the 2017 and 2020 sample cycle (Figure 2).

Given the increasing trend of iodine deficiency and majority of US women were not taking any iodine supplement, there is a need for intervention through encouraging dairy consumption, iodine added food and salt or iodine supplements to thwart the declining trend of iodine intake, particularly for women of reproductive ages, pregnant and lactating. Long-term savings from health care cost related to iodine inadequacy may outweigh the economic cost of iodine intervention. However, ATA advises against the ingestion of iodine and kelp supplements containing in excess of 500 mcg iodine daily (44).

Limitations

USDA, FDA and ODS-NIH release 2 of food iodine concentration has only 425 food items available while more than 6000 food items were reported in NHANES nutritional survey. Therefore, our mean estimations of iodine concentration of 29 FPED food groups, salt and water, might have over- or underestimated iodine intake from the foods consumed by NHANES participants despite our best effort for mapping the means of food groups. Iodine concentration of the food items might also change with time. Infrequent intake of high iodine concentration food such as seafood might be missed by NHANES 24-hrs recalls and can underestimate the iodine intake of some NHANES participants (11). The relatively small number of pregnant and lactating women in this study makes detailed analyses difficult and the results for these two groups may not represent that of US population. Other cofounding factors, such as geographic variation of iodine concentration in food items that were not considered (38) might also affect the outcome of usual intake estimation.

CONCLUSIONS

Median dietary iodine intake of US women declined significantly from the 2011-2012 to 2017-2020 NHANES sample cycles. The median usual intakes of iodine were 196.4, 164.8 and 188.9 mcg/24hrs for US girls 14 years and younger, non-pregnant, non-lactating women of reproductive ages 15-49 years old and women 50 years and older respectively in 2017-2020 sample years. The median usual intakes of pregnant and lactating women were 235.1 and 230.4 mcg/24 hrs with 10.2% below EAR for pregnant and 40.3% below EAR for lactating women during the 2017-2020 period respectively. The iodine intake estimated from UIC declined as well. Insufficiencies estimated from UIC using WHO criteria were 33.8%, 48.8% and 45.3% for US girls 14 years and younger, non-lactating women of reproductive ages 15-49 years old and women 50 years and older respectively in 2017-2020 sample years. 63.3% and 31.3% pregnant and lactating women had insufficient iodine intake based on UIC. Though proportion of US women 15 years and older who took iodine supplement increased, majority of US women, including pregnant and lactating, were not taking any iodine supplement during this period. Percentages of excessive iodine intake levels based on UIC ranged from 16.7% to 23.1%, 9.5% to 14.1%, 14.6% to 18.9% for US girls 14 years and younger, non-pregnant, nonlactating women 15-49 years and 50 years and older in 2017-2020 sample years. Continued declines in milk consumption was identified as one of the major contributors to the decline of iodine intake in US girls and women. Increased inadequacies of iodine intake estimated from both food intake and UIC between 2011 and 2020 can have significant future health implication for US women and deserve public health attention.

Acknowledgements

Hongbing Sun contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript and is responsible for the final content of the article. Connie M Weaver contributed to the interpretation of the results and writing of the manuscript. All authors (HS, CMW) have read and approved the manuscript. The authors wish to thank Elizabeth Pearce from Boston University for her critical and constructive comments which helped improve this manuscript significantly.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

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Figure captions

Figure 1. a, median usual intakes of iodine and b, median urinary iodine concentration (UIC) vs. races and three age groups of US females in 2017-2020 cycles. Label abbreviation: Mexican A, Mexican Americans, NM Hispanic, Non-Mexican Hispanic Americans.

Figure 2. a, Percentage trends and b, percentages by races of US girls, nonpregnant-nonlactating, pregnant and lactating US women who took iodine supplement between 2011-2012 and 2017-2020 sample cycles.

Table 1. Demographic data of US girls and women between 2011 and 2020 analyzed in this study

Category\year	2011-2012	2013-2014	2015-2016	2017-2018	2017-2020	Total count
Number of girls and women with dietary data by age group						
<15 yrs old	1,198	1,095	1,084	894	1,524	5,795
15-49	1,587	1,785	1,692	1,445	2,392	8,901
>=50	1,168	1,253	1,265	1,302	2,069	7,057
total	3,953	4,133	4,041	3,641	5,985	21,753
Number of pregnant and lactating women with dietary data (ages 20-43 yrs old)						
pregnant	49	62	63	48	77	299
lactating	21	40	42	38	54	195
Number of girls and women with dietary data by races						
[1]MA	511	704	813	554	778	3,360
NMH	413	411	552	310	570	2,256
White	1,247	1,552	1,238	1,252	2,055	7,344
Black	1,139	873	888	863	1,630	5,393
Other	643	593	550	662	952	3,400
Numbers of pregnant and lactating women and all others with UIC data						
pregnant	18	20	22	20	26	106
lactating	9	12	11	11	17	60
All other	1247	1,347	1,547	1,430	2,319	7,890

Race[1]: MA, Mexican American, NMA, non-Mexican Hispanic, White, Non-Hispanic White, Black, Non-Hispanic Black, Other, Other Races - Including Multi-Racial.

Table 2. Median usual intakes (mcg/24 hrs) and adequacy percentages of dietary and dietary plus supplementary iodine of US girls and women

	Diet only	Diet+supplement	Inadequacy%	Excessive%
Girls 14 years and younger				
2011-2012	212.2±4.2	224.3±4.7	0.5±0.3	19.6±2.4
2013-2014	195.8±5.2	207.3±5.9	0.6±0.2	15.7±1.2
2015-2016	197.7±8.0	203. 7±8.1	0.6±0.4	13.8±1.2
2017-2018	189.6±3.4	196.4±3.7	0.8±0.4	11.8±1.3
2017-2020	188.9±3.5	196.4±3.8	1.1±0.6	12.4±1.0
p-trend	0.044(-)	0.027(-)	0.036(+)	0.026(-)
Non-pregnant, non-lactating women 15 to 49 years old				
2011-2012	175.6±4.9	184.1±5.2	5.8±1	0±0
2013-2014	172.9±3.4	184.7±3.7	9.3±2.7	0.01±0.05
2015-2016	167.1±6.3	181.6±7.8	4.5±1.4	0±0
2017-2018	156.3±3.9	170.4±4.3	9.1±1.7	0±0
2017-2020	150.3±2.4	164.8±2.7	9.9±1.2	0±0
p-trend	0.003(-)	0.022(-)	0.363(+)	---
Non-pregnant, non-lactating women 50 years and older				
2011-2012	174±5	202±7.7	7.6±1.8	0.02±0.04
2013-2014	168.8±5.3	193.4±5.9	6.9±1.3	0±0
2015-2016	162.2±7.8	196.5±16.4	15.9±4.3	0.92±1.66
2017-2018	161.5±4.5	205.6±13.4	4.9±1.9	0.01±0.01
2017-2020	153.9±4.7	188.9±6.2	7.2±1.5	0.01±0.01
p-trend	0.003(-)	0.584(-)	0.87 (+)	
Pregnant women				
2011-2012	186.8 ±18.7	203.8 ±11.5	14.6 ±7.5	0 ±0
2013-2014	162.4 ±10.3	190.4 ±17.9	23.7 ±5.5	0 ±0
2015-2016	239.4 ±22	220.7 ±18	5.6 ±2.7	0 ±0
2017-2018	216.2 ±40.6	264.1 ±47.5	11.7 ±7.4	0 ±0.1
2017-2020	215.7 ±27.1	235.1 ±28.4	10.2 ±4.6	0 ±0
p-trend	0.17(-)	0.14(+)	0.40(-)	---
Lactating women				
2011-2012	257.8 ±21.9	259.6±21.6	0 ±5.2	0 ±0
2013-2014	215.6 ±36.6	219.1±35.1	44.8 ±18.8	0 ±0
2015-2016	225.3 ±21.4	281.3±31.3	24.6 ±8.5	0 ±0.1
2017-2018	202.7 ±41.3	263.3±46.3	26.9 ±18.1	0 ±0
2017-2020	181 ±28.7	230.4±37.2	40.3 ±14.8	0 ±0
p-trend	0.02(-)	0.07(-)	0.85(-)	---

Note: [1]Numbers following the ± sign are the standard errors; [2]Inadequacy: percentage of intake below EAR; Excessive: percentage of intake above the up limit. For age groups: Ages <=3 years (yrs) old, EAR-65 mcg/24hrs, up limit (UL)- 200 mcg/24hrs; 4-8 yrs old, EAR-65, UL-300 mcg/24hrs; 9-13 yrs old, EAR- 74, UL-600 mcg24 hrs; 14-18 yrs old: EAR- 95, UL- 900 mcg/24hrs:>19 yrs old, EAR-95, UL-1100 mcg/24hr. For lactating women: 209 mcg/day, for pregnant women: 160 mcg/day. EARs are from Institute of Medicine.[35] [3]p- trend: significance level of regression trend over the five sample-cycle years and "+" signs within the parentheses indicate a growing trend while "-" signs indicate a reducing trend.

Table 3. Medians (ug/l) and sufficiency percentages of urinary iodine concentration of US girls and women

	[1]Median UIC	[2]Total insufficiency %	Mild deficiency %	Moderate deficiency %	Severe deficiency %	Excessive %
Girls 14 years and younger						
2011-2012	142.6±11.3	34.5±4	19.4±2.9	12.2±2.8	2.9±1.9	21.8±4.6
2013-2014	152.9±11.5	27.1±3.7	19.5±2.9	7.1±2.6	0.5±0.4	16.7±1.7
2015-2016	157.2±13.4	31.4±2.9	20.7±1.4	9.8±2	1±0.5	23.1±2.7
2017-2018	141.6±15.8	36.5±3.3	20.1±2	13.4±2.4	3.1±1.6	22.4±3.1
2017-2020	143.8±10.4	33.8±3	19.9±1.9	11.3±1.7	2.6±1.3	20.9±2.5
[3]p-trend	0.746(-)	0.562(+)	0.391 (+)	0.635(+)	0.665(+)	0.703(+)
Non-pregnant, non-lactating women 15 to 49 years old						
2011-2012	107.9±7.9	46.5±2.9	24.5±2.5	19.6±2.3	2.5±0.9	13.7±2.2
2013-2014	103.7±6.7	47.9±2.6	27.5±2.1	17.7±1.8	2.7±0.8	14.1±2.5
2015-2016	101.2±6.4	48.9±2.8	27.9±2.3	17.6±2.1	3.3±1.2	13.1±2.4
2017-2018	98.4±5.6	50.7±3	26.8±3.4	16.1±1.7	7.8±1.2	9.5±1.8
2017-2020	102.8±5.3	48.8±2.9	27.9±2.8	15.1±1.5	5.8±1	10±1.6
p-trend	0.186(-)	0.131(+)	0.212 (+)	0.004(-)	0.103(+)	0.053(-)
Non-pregnant, non-lactating women 50 years and older						
2011-2012	133.7±10.2	36.5±3.7	25.4±3.4	11.1±2.6	1.7±1.2	14.6±2.3
2013-2014	125.9±7.8	39.4±3.1	26.1±2.2	12.2±2.6	1±0.3	18.6±2.8
2015-2016	132±11.8	38.1±3.6	25.8±3.5	9.9±2.2	1.2±0.8	18.9±3.3
2017-2018	118±13.1	44.7±3.7	31.2±2.7	10.3±1.8	2±1	16.2±2.7
2017-2020	119.5±11.2	45.2±2.7	30.2±2.5	12.4±1.9	1.8±0.7	16.7±2.4
p-trend	0.097(-)	0.032(+)	0.066(+)	0.855(+)	0.398(+)	0.784(+)
[4]Pregnant women						
2011-2012	123.1±30.7	52.9±14.7				0
2013-2014	144.3±36.3	53.8±13.6				12.6±12.1
2015-2016	144.1±22.4	55.1±11.1				4.8±3.7
2017-2018	156±54.7	57.2±16.7				9.3±6.1
2017-2020	131.4±46.8	63.2±13.1				11.7±7.8
p-trend	0.561(+)	0.024(+)				
Lactating women						
2011-2012	70±30.2	74±13.9				
2013-2014	80.5±57.6	43.5±24.3				
2015-2016	93±19.2	73.9±15				
2017-2018	126±23.6	17.7±12.1				
2017-2020	122.1±20.2	31.3±13.6				
p-trend	0.0.13(+)	0.194(-)				

Note: [1]Median UIC: Numbers following the ± sign are standard errors. For girls and non-pregnant, non-lactating women, UIC <100 ug/L was considered iodine insufficient, 50-99 µg/L mildly deficient, 49-20 ug/l moderately deficient, <20 ug/L severely deficient and above 300 ug/l excessive. For lactating and pregnant women, UIC<100 ug/L and <150 ug/L were considered iodine insufficient respectively.[25] For pregnant women, UIC above ≥500 µg/L was considered excessive. [3]p- trend: significance level of regression trend over the five sample-cycle years and "+" signs indicate a growing trend while "-" signs indicate a declining trend. [4]Median UICs for pregnant and lactating women were not weighted for population because of small sample size.

Table 4. Mean percentage (%) contributions of 11 main food (including water and salt) categories to dietary iodine intake of US girls and women

	Total fruit	[1]Total veg	Whole grain	Refined grain	[2]total pf_mps	eggs	milk	yogurt	cheese	water	salt
Mean percentage contributions of 11 food categories to dietary iodine in the five sample cycles											
2011-2012	0.1±0.01	0.5±0.01	6.4±0.19	18.8±0.39	5.4±0.4	3±0.14	37.7±0.86	4.1±0.43	7.5±0.21	4.9±0.2	10.5±0.21
2013-2014	0.1±0	0.5±0.01	6.3±0.15	19.6±0.39	6.6±0.6	3.4±0.13	33.5±0.66	4.6±0.32	8.1±0.19	5.3±0.17	10.9±0.16
2015-2016	0.2±0	0.5±0.02	6.4±0.21	18.9±0.5	6.1±0.45	4±0.15	33.3±0.96	5.2±0.34	7.3±0.29	6±0.22	11.2±0.24
2017-2018	0.1±0	0.6±0.02	6.2±0.26	20.5±0.48	6.3±0.53	4.2±0.26	31±0.79	4.3±0.38	8±0.26	6.1±0.16	11.5±0.26
2017-2020	0.2±0	0.6±0.02	6.3±0.21	19.9±0.35	6.1±0.39	4.4±0.21	31.3±0.61	4.4±0.3	7.9±0.2	6.2±0.11	11.8±0.19
[3]p-trend	0.089 +	0.012+	0.487-	0.213+	0.527+	0.004+	0.035-	0.867+	0.614+	0.015+	<0.01+
Mean percentage contributions of 11 food categories to dietary iodine intake of three age groups and all ages											
<15 yrs old	0.2±0	0.3±0.01	5.6±0.17	18.2±0.28	2.6±0.19	2.3±0.09	48.6±0.57	3.9±0.3	6.9±0.16	2.5±0.06	8.7±0.11
15-49 yrs	0.1±0	0.6±0.01	5.8±0.15	21.4±0.25	6.4±0.27	4.1±0.15	28.6±0.52	3.9±0.22	8.9±0.17	6.8±0.11	12.2±0.12
>50 yrs	0.2±0	0.6±0.01	7.4±0.17	17.9±0.27	7.6±0.38	4.1±0.12	31.4±0.56	5.7±0.31	6.9±0.2	6±0.13	11.2±0.14
All ages	0.2±0	0.6±0.01	25.8±0.18 (all grain)		6.1±0.22	3.8±0.09	45.7±0.4 (all dairy)			5.7±0.08	11.2±0.1
[4]Abt et al.[10]	2	1	17 (all grain)		3	5	49 (all dairy)			0	0
Percentage differences of contributions from 11 food categories to dietary Iodine between 2011-2012 and 2017-2020											
<15 yrs old	0.02±0.01	0.02±0.02	2.04±0.46	1.3±0.7	0.62±0.72	0.46±0.23	-6.72±1.49	0.84±1.12	-0.34±0.5	1.09±0.17	0.66±0.3
15-49 yrs	0±0.01	0.12±0.03	-0.4±0.46	1.41±0.69	0.48±0.65	1.6±0.45	-6.47±1.74	-0.34±0.66	0.35±0.45	1.49±0.35	1.72±0.38
>50 yrs	0.01±0.01	0.05±0.04	-1.01±0.6	0.78±0.86	0.85±0.94	1.5±0.36	-6.32±1.44	0.74±0.84	1.02±0.67	1.14±0.43	1.25±0.38
All ages	0.01±0.01	0.08±0.02	-0.09±0.28	1.07±0.52	0.69±0.55	1.35±0.25	-6.42±1.05	0.3±0.52	0.4±0.29	1.27±0.23	1.32±0.28

Note: [1]Total_veg: total vegetables; [2]TOTAL PF_MPS: Total Meat, Poultry and Seafood. [3]p-trend: significance level of regression trend, "+" signs indicate a growing trend while "-" signs indicate a reducing trend. [4]Abt et al. data were extracted from reference #10 and are for population (both men and women) between years 2008 and 2012.

Appendix Table 1. Iodine concentrations of 29 food groups of FPED, tap water and sodium salt

Abbreviation	Name	Unit	Weight range grams per cup	Median weight grams per unit	iodine mcg per 100 grams
F_CITMLB	Citrus, Melons, and Berries	cup eq.	145-185	165	0.2
F_OTHER	Other Fruits	cup eq.	110-155	145	0.2
F_JUICE	Fruit Juice	cup eq.		250	0.1
F_TOTAL	Total Fruit	cup eq.	70-250		
V_DRKGR	Dark Green Vegetables	cup eq.	70-170	140	0.2
V_REDOR_TOMATO	Tomatoes	cup eq.	120-245	170	0.51
V_REDOR_OTHER	Other Red and Orange Vegetables	cup eq.	115-245	135	0.51
V_REDOR_TOTAL	Total Red and Orange Vegetables	cup eq.	120-245		
V_STARCHY_POTATO	Potatoes	cup eq.	120-155	137.5	0.6
V_STARCHY_OTHER	Other Starchy Vegetables	cup eq.	60-175	160	0.5
V_STARCHY_TOTAL	Total Starchy Vegetables	cup eq.	60-175		
V_OTHER	Other Vegetables	cup eq.	60-210	150	0.5
V_TOTAL	Total Vegetables	cup eq.	57-245		
V_LEGUMES	Beans and Peas	cup eq.	60-175	117.5	0.3
G_WHOLE	Whole Grains	oz. eq.		28.35	50
G_REFINED	Refined Grains	oz. eq.		28.35	25
G_TOTAL	Total Grains	oz. eq.			
PF_MEAT	Meat	oz. eq.		28.35	3.6

PF_CUREDMEAT	Cured Meat	oz. eq.		28.35	3.6
PF_ORGAN	Organ Meat	oz. eq.		28.35	16
PF_POULT	Poultry	oz. eq.		28.35	2
PF_SEAFD_HI	Seafood High in n-3 Fatty Acids	oz. eq.		28.35	60
PF_SEAFD_LOW	Seafood Low in n-3 Fatty Acids	oz. eq.		28.35	60
PF_MPS_TOTAL	Total Meat, Poultry, and Seafood	oz. eq.			
PF_EGGS	Eggs	oz. eq.		28.35	50
PF_SOY	Soy Products	oz. eq.		28.35	0.1
PF_NUTSDS	Nuts and Seeds	oz. eq.		28.35	0.7
PF_LEGUMES	Beans and Peas	oz. eq.		28.35	0.5
PF_TOTAL	Total Protein Foods	oz. eq.			
D_MILK	Milk	cup eq.		245	35
D_YOGURT	Yogurt	cup eq.		245	45
D_CHEESE	Cheese	cup eq.		42.75	50
D_TOTAL	Total Dairy	cup eq.			
OILS	Oils	grams		1	0.1
SOLID_FATS	Solid Fats	grams		1	0.1
ADD_SUGARS	Added Sugars	tspeq		4.2	0.4
A_DRINKS	Alcoholic Drinks	no. of drinks		319	0.98
Sodium salt	11% Na intake from home	grams		100	677.9
Tap water		grams		100	0.92

Note: Rows with _TOTAL are food categories that participants' iodine intake can be summarized from individual food groups (see text for details).