Second National Report on Biochemical Indicators of Diet and Nutrition in the U.S. Population 2012

Executive Summary



National Center for Environmental Health
Division of Laboratory Sciences

Background

The National Report on Biochemical Indicators of Diet and Nutrition in the U.S. Population is a series of publications that provide ongoing assessment of the U.S. population's nutrition status by measuring blood and urine levels of diet-and-nutrition biochemical indicators.

This is the second report in this series. The Centers for Disease Control and Prevention's (CDC) Division of Laboratory Sciences at the National Center for Environmental Health (NCEH/DLS) conducted the laboratory analyses for 58 biochemical indicators presented in this 2012 report. CDC measured these indicators in specimens from a representative sample of the U.S. population during all or part of the four-year period from 2003 through 2006. Where available, data are also presented on changes of biochemical indicator levels over time since 1999. Similarly, data are also presented on the prevalence of low or high biochemical indicator levels during 2003–2006, and on changes in the prevalence over time since 1999.

The first report of this series was published in July 2008 and it contains information on 27 biochemical indicators from all or part of the four-year period from 1999 through 2002. Both reports can be accessed online: http://www.cdc.gov/nutritionreport.

Biochemical indicator sections	New report features	New biochemical indicators
• Water-soluble vitamins	• Central 95% reference intervals	• Vitamin B6
• Fat-soluble vitamins and nutrients	• Graphic representation of age patterns	• Vitamin C
• Trace elements (iron indicators and iodine)	• Levels over time	• Fatty acids
• Isoflavones and lignans	• Prevalence estimates	• Iron status: Transferrin receptor and body iron

The specimens for the *Second Nutrition Report* were collected by CDC's National Health and Nutrition Examination Survey (NHANES), which is conducted by the National Center for Health Statistics (NCHS). NHANES is a series of surveys designed to collect data on the health and nutrition status of the U.S. population.

This report covers one important facet in the assessment of nutrition status of the U.S. population: biochemical measurements. Other nutrition-related aspects from NHANES, such as dietary intake, supplement usage, hematologic measurements, and anthropometric body measurements are not covered.

Public health uses

The primary objective of the *Second Nutrition Report* is to inform public health scientists and policy makers about the levels of biochemical indicators of diet and nutrition in the general U.S. population and in selected subpopulations. These data will help physicians, scientists, and public health officials assess inadequate or excess intake and will inform analyses on the relation between biochemical indicators and health outcomes. Other objectives and potential public health uses of the information include the following:

- Establishing and improving upon existing population reference levels that can be used to determine whether a person or a group of people has an unusually high or low level of a biochemical indicator of diet and nutrition.
- Determining whether the nutrition status of special population groups, such as minorities, children, women of childbearing age, or the elderly is different from that of other groups, or whether such nutrition status needs improvement.
- Tracking trends over time in the population's biochemical indicator levels.
- Assessing the effectiveness of public health efforts to improve the diet and nutrition status of the U.S. population.
- Guiding research to perform more in-depth analyses of the NHANES data and to generate hypotheses for future nutrition and human health studies.

Data presented for biochemical indicators

The *Second Nutrition Report* contains tables and figures of descriptive statistics on the distribution of blood and urine levels during all or part of the four-year period from 2003 through 2006 for each diet-and-nutrition biochemical indicator. Statistics include unadjusted geometric means and selected percentiles with confidence intervals. For some biochemical indicators, additional information is included, as available, in the form of:

- Tables and figures describing biochemical indicator levels across survey cycles during all or part of the eight-year period from 1999 through 2006. Statistics include unadjusted geometric means and selected percentiles with confidence intervals.
- Tables describing the prevalence of low or high levels of selected biochemical indicators during all or part of the four-year period from 2003 through 2006 and tables describing the prevalence across survey cycles during all or part of the eight-year period from 1999 through 2006. Statistics include unadjusted percentages with confidence intervals and estimated total number of persons affected.

Interpreting the data



Blood and urine levels of biochemical indicators can help in assessing the adequacy of intake for the U.S. population. These measurements indicate cumulative intakes from foods, some fortified with micronutrients (e.g., iron, thiamin, riboflavin, niacin, folate, vitamin A, vitamin D), and from dietary supplements that contain vitamins, minerals, or both. However, blood or urine levels of biochemical indicators can also be influenced by factors other than diet, such as various diseases or exposures. For those nutrients without defined adequate intakes (e.g., carotenoids, isoflavones), biochemical indicators are useful for assessing intake without regard to adequacy.

Dietary deficiencies are well documented, and they have characteristic signs and symptoms. In addition, recent findings have determined that less than optimal biochemical levels have been associated with risks of adverse health effects. These health effects include cardiovascular disease, stroke, impaired cognitive function, cancer, eye diseases, poor bone health, and other conditions. Adverse health effects, including toxicity, are also possible from consuming excess amounts of certain nutrients and data to assist in the assessment of excessive intake is a feature of this report.

Determining the levels of a biochemical indicator that may indicate risk for disease and the levels that are of negligible health concern requires future research studies that are separate from this report. In collaboration with other agencies and institutions, CDC encourages, and itself conducts research on the relationship between biochemical indicators and health effects.

New information on prevalence of nutrient deficiencies

In NHANES 2003-2006, 10% or less of the general U.S. population had nutrition deficiencies for selected indicators (Fig. 1). However, for most nutrition indicators, the prevalence varied by age, gender, or race/ethnicity. For example, children and adolescents were rarely deficient in vitamin B12 (< 1%), while older adults were more likely to be deficient (4%). Men were more likely to be vitamin C deficient (7%) compared to women (5%). Non-Hispanic black (31%) and Mexican-American (12%) people were more likely to be vitamin D deficient compared to non-Hispanic white people (3%).

- Vitamin B6 (serum pyridoxal-5'-phosphate < 20 nmol/L), iron (serum body iron < 0 mg/kg), and vitamin D (serum 25-hydroxyvitamin D < 30 nmol/L) are the three nutrients assessed in this report with the highest prevalence of deficiency.
- Vitamin A (serum retinol < 20 µg/dL), vitamin E (serum *alpha*-tocopherol < 500 µg/dL), and folate (red blood cell folate < 95 ng/mL) are nutrients with the lowest prevalence of deficiency of less than 1%.
- Vitamin C (serum ascorbic acid < 11.4 µmol/L) and vitamin B12 (serum cobalamin < 200 pg/mL) are nutrients with intermediate prevalence of deficiency.

Where we have data from 8 years of NHANES (1999–2006), we noticed that the prevalence of nutrient deficiencies hasn't changed over that time period. Future reports may provide information on nutrient levels extending over a longer period of time.

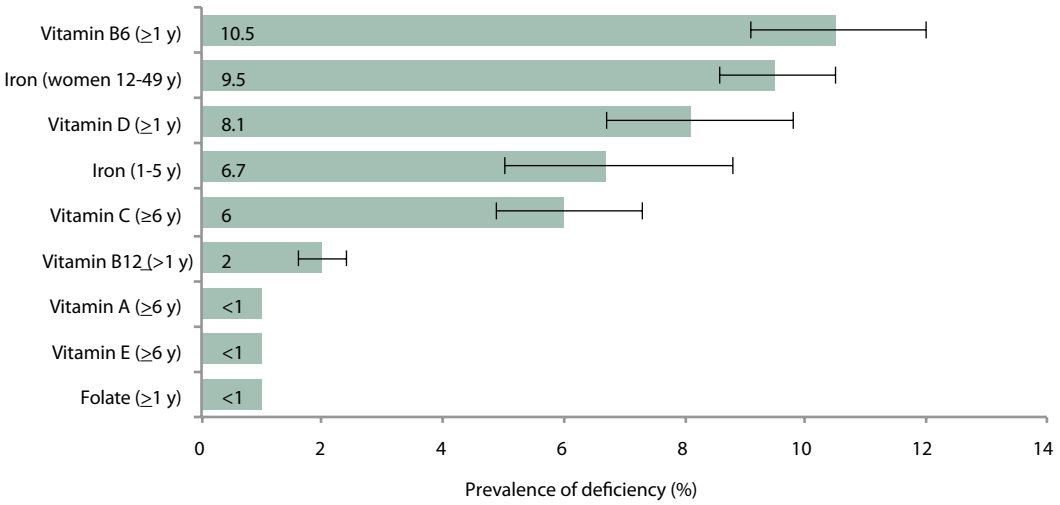


Figure 1. *Prevalence estimates of nutrient deficiencies in U.S. persons, National Health and Nutrition Examination Survey, 2003–2006. Error bars represent 95% confidence intervals. Nutrition indicators were measured in different age (e.g., 1 y and older, 6 y and older) and population groups (e.g., women 12-49 y of age, children 1-5 y of age). Cutoff values used to estimate prevalence are: serum pyridoxal-5'-phosphate < 20 nmol/L, serum body iron < 0 mg/kg, serum 25-hydroxyvitamin D < 30 nmol/L, serum ascorbic acid < 114. µmol/L, serum cobalamin < 200 pg/mL, serum retinol < 20 µg/dL, serum alpha-tocopherol < 500 µg/dL, and red blood cell folate < 95 ng/mL.*

Folate levels rise after food fortification, decreasing folate deficiency to < 1%

Folate belongs to the group of water-soluble B vitamins that occur naturally in leafy green vegetables, fruits, and dried beans and peas. Folic acid is the synthetic form of folate found in supplements and added to fortified foods. Serum folate levels provide information on recent intake, while red blood cell (RBC) folate levels are indicative of body folate stores and long-term nutrition status. Adequate folate status is especially important during pregnancy, infancy, and other periods when cells rapidly divide and grow. To reduce the risk of neural-tube defects in newborns, the U.S. Food and Drug Administration introduced mandatory folic acid fortification of enriched cereal grain products in 1998.

Blood folate levels in the U.S. population showed the following demographic patterns:

- Of all age groups, older persons had the highest blood folate levels.
- Females had generally higher levels than males.
- Non-Hispanic blacks had the lowest, non-Hispanic whites had the highest, and Mexican Americans had intermediate folate status.

Continuous monitoring of the effect of the U.S. folic acid fortification program on blood folate levels is of great public health interest.

- Post 1998, blood folate levels increased by about 50% across race/ethnic groups (Fig. 2). From 1999–2002 to 2003–2006, blood folate levels decreased slightly (< 10%) in each race/ethnic group, likely as a result of the intentional small reduction in the amount of folic acid added to foods during this time period (Fig. 2).
- Before fortification, folate deficiency was about 10–12% in women of childbearing age, but after fortification, folate deficiency dropped to less than 1% in the U.S. population and in women of childbearing age of all race/ethnic groups.

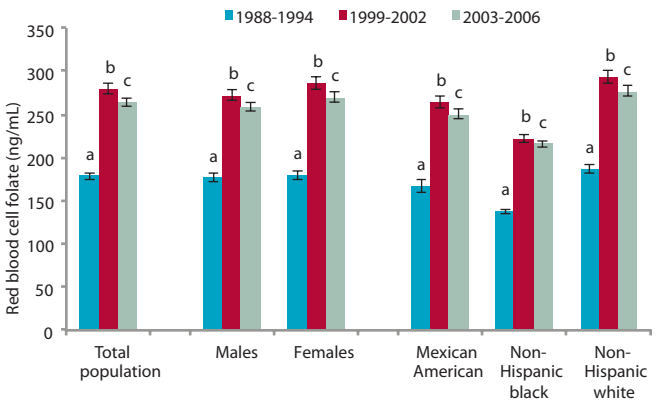


Figure 2. *Age-adjusted geometric mean levels of RBC folate in the U.S. population aged 4 years and older by gender or race/ethnicity, National Health and Nutrition Examination Survey, 1988–2006. Error bars represent 95% confidence intervals. Within a demographic group, bars not sharing a common letter differ ($p < 0.05$).*

Vitamin D deficiency is closely related to race/ethnicity

Vitamin D is naturally found in only a few foods, such as fish-liver oils, fatty fishes, mushrooms, egg yolks, and liver. In the United States, vitamin D is commonly added to milk and other foods. Ultraviolet light from the sun helps people photosynthesize vitamin D in the skin, which is then transported to the liver and converted to 25-hydroxyvitamin D. Clinicians use serum 25-hydroxyvitamin D to determine a person's vitamin D status because it is a good reflection of cumulative effects of exposure to sunlight and dietary intake. Vitamin D is essential for good bone health, and it may be important for muscle strength and protecting against cancer and type 2 diabetes. These benefits of vitamin D are currently under active investigation.

Serum 25-hydroxyvitamin D levels in the U.S. population showed the following demographic patterns:

- Levels generally decreased as age increased.
- Males and females had similar levels.
- Among the three race/ethnic groups, non-Hispanic blacks had the lowest 25-hydroxyvitamin D levels and non-Hispanic whites had the highest levels.

Clinical data show that non-Hispanic blacks have better bone health–greater bone density and fewer fractures–than other race/ethnic groups. However in NHANES 2003-2006, non-Hispanic blacks had the highest prevalence of vitamin D deficiency (serum 25-hydroxyvitamin D levels less than 30 nmol/L) (Fig. 3). Further research is needed to explain this unusual finding. Non-Hispanic blacks and Mexican Americans had the highest prevalence of low serum 25-hydroxyvitamin D levels categorized as at-risk for inadequacy (30 to less than 50 nmol/L) compared to non-Hispanic whites (Fig. 3).

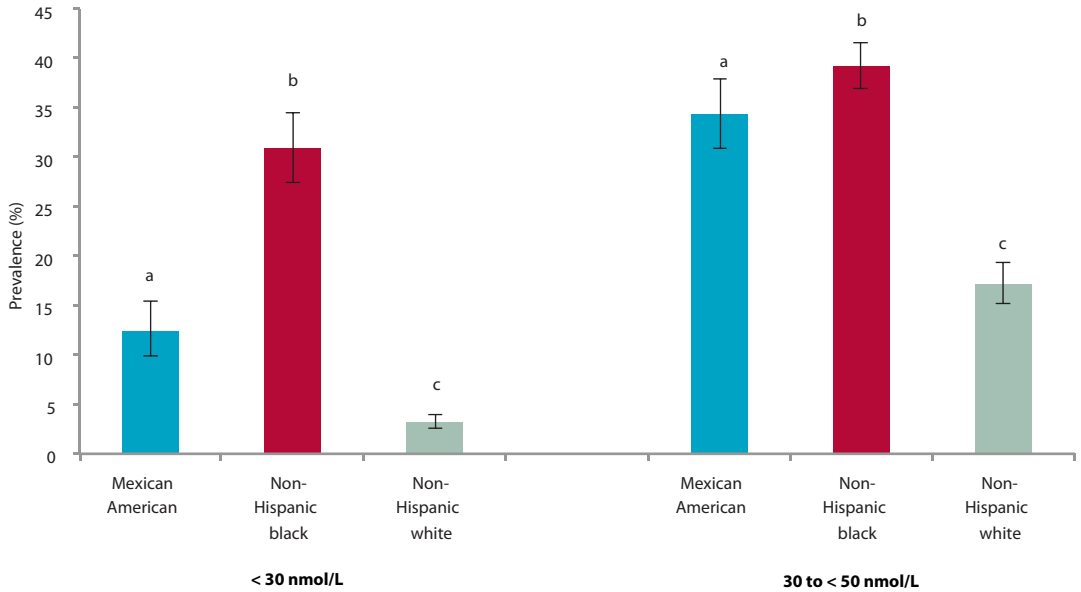


Figure 3. *Age-adjusted prevalence estimates of serum 25-hydroxyvitamin D levels less than 30 and 30 to less than 50 nmol/L in the U.S. population aged 1 year and older by race/ethnicity, National Health and Nutrition Examination Survey, 2003–2006. Error bars represent 95% confidence intervals. Within each vitamin D status category, bars not sharing a common letter differ ($p < 0.05$).*

First-time measurements of 24 plasma fatty acids, including heart-healthy fatty acids, in the U.S. population

Most fatty acids can be synthesized by the human body from carbohydrates. However, humans are incapable of *de novo* synthesis of n-6 and n-3 polyunsaturated fatty acids. Thus, linoleic (18:2n-6) and *alpha*-linolenic (18:3n-3) acid are called "essential" polyunsaturated fatty acids. Both of these fatty acids are metabolized to longer-chain, more highly unsaturated forms. Fatty acids with no double bonds are referred to as saturated fatty acids, while those with one double bond are monounsaturated fatty acids. Currently, intense debate surrounds the question of whether reduction in dietary saturated fatty acids reduces the risk of cardiovascular disease. Lowering dietary intake of saturated fatty acids to no more than 10% of caloric intake and replacing them with mono- and polyunsaturated fatty acids is recommended to reduce the risk of cardiovascular disease.

These first-time plasma fatty acids levels in the U.S. population showed the following demographic patterns:

- In general, younger adults had lower levels of fatty acids.
- Plasma levels of fatty acids were generally similar in men and women.
- For most fatty acids, no consistent race/ethnic pattern was found.

Heart-healthy n-3 polyunsaturated fatty acid levels in plasma differ by race/ethnicity:

Geometric mean levels of eicosapentaenoic acid (EPA), which is typically derived from seafood and supplements, were higher in fasted non-Hispanic blacks and whites compared to Mexican-American adults (Fig. 4, Panel A). In addition, plasma levels of the related long-chain polyunsaturated docosahexaenoic acid (DHA) were higher in non-Hispanic black compared to Mexican-American and non-Hispanic white adults (Fig. 4, Panel B). Tracking fatty acid levels over time will show progress toward more heart-healthy diets.

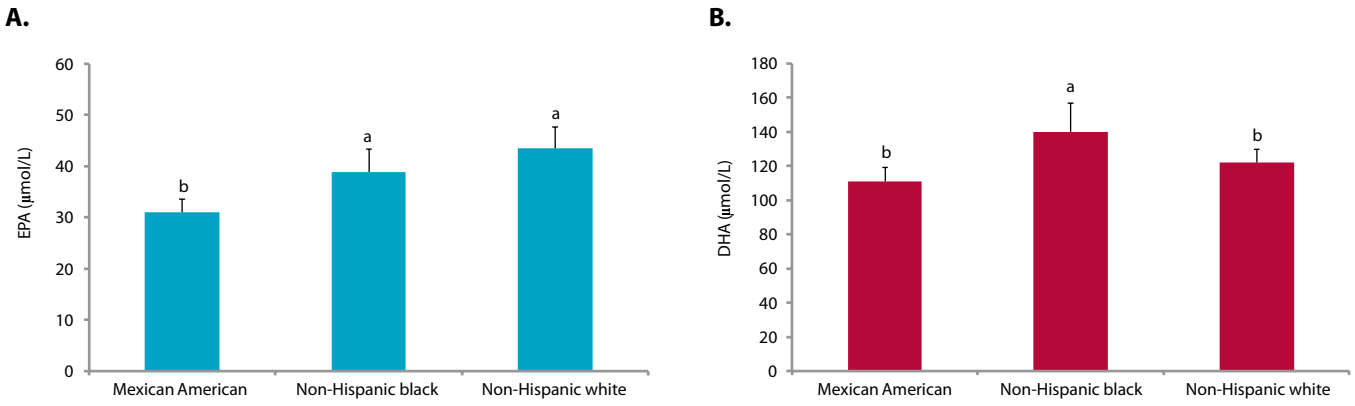


Figure 4. *Geometric mean plasma levels of eicosapentaenoic (EPA, panel A) and docosahexaenoic (DHA, panel B) acid in the U.S. population from fasted adults aged 20 years and older by race/ethnicity, National Health and Nutrition Examination Survey, 2003-2004. Error bars represent 95% confidence intervals. Bars not sharing a common letter differ ($p < 0.05$).*

First-time measurement of new iron marker improves assessment of iron deficiency in Americans

Iron is needed for the formation of hemoglobin, the protein in red blood cells that carries oxygen to tissues. Iron deficiency (ID) is linked to adverse consequences, such as reduced physical capacity, poor pregnancy outcomes, and negative effects on cognitive development among infants and adolescents and can progress to anemia if not treated. Low serum ferritin is a sensitive indicator of ID, but ferritin is affected by inflammation and levels do not track well with the progression of ID to anemia once iron stores are depleted. Serum soluble transferrin receptor (sTfR) levels start to increase after iron stores are depleted; they are indicative of functional ID and less affected by inflammation. Measuring this new marker and calculating the ratio of sTfR to ferritin, so-called body iron, allows assessment of the full spectrum of ID in the presence of inflammation.

Levels of serum ferritin and sTfR in the U.S. population showed the following demographic patterns:

- Children had the lowest ferritin and highest sTfR levels compared to other age groups.
- Regardless of the indicator selected, the likelihood of being iron deficient varied by race/ethnic group.
- While children and women of childbearing age were at risk for ID, men were at risk for iron excess.

New data from NHANES 2003–2006 allowed for the first time assessment of the iron status of children and women of childbearing age using body iron. Body iron is in a positive balance (≥ 0 mg/kg) when there is residual storage iron or in a negative balance (< 0 mg/kg) when there is functional ID.

The prevalence of ID based on low body iron (< 0 mg/kg) was higher in Mexican-American children compared to non-Hispanic black and non-Hispanic white children; it was higher in Mexican-American and non-Hispanic black women aged 12–49 years compared to non-Hispanic white women (Fig. 5).

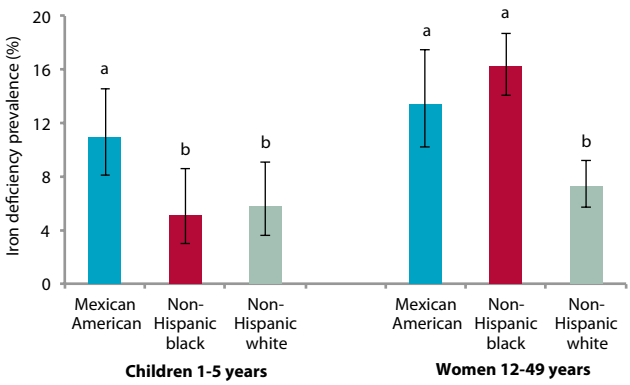


Figure 5. *Age-adjusted prevalence estimates of low body iron (< 0 mg/kg) in children and women by race/ethnicity, National Health and Nutrition Examination Survey, 2003–2006. Error bars represent 95% confidence intervals. Bars not sharing a common letter differ within children and women (p < 0.05).*

Women of childbearing age have iodine levels bordering on insufficiency

Iodine, a trace element found in soil, is an essential component of the thyroid hormones involved in regulating the body's metabolic processes related to normal growth and development. Across the world, iodized salt and seafood are the major dietary sources of iodine. In the United States, where addition of iodine to salt is not mandatory, most people get their iodine from dairy products and bread. Iodine deficiency is the most preventable cause of mental retardation in the world. Iodine deficiency disorders include mental retardation, hypothyroidism, goiter, cretinism, and varying degrees of other growth and developmental abnormalities. Most dietary iodine absorbed in the body eventually appears in the urine; thus, urine iodine excretion is recommended for assessing recent dietary iodine intake.

Urine iodine levels in the U.S. population showed the following demographic patterns:

- The lowest levels were observed in young women, while the highest levels were observed in children.
- No consistent pattern was observed with regard to race/ethnicity.
- Urine iodine levels have been relatively stable since the late 1980s.

The iodine intake of the U.S. population appeared to be adequate on the basis of median urine iodine levels. However, women aged 20–39 years had the lowest iodine intake, just slightly above insufficient intake (Fig. 6). Young women merit special attention to ensure the best possible brain development of the fetus during pregnancy.

While no age group had a median urine iodine level that represented excessive iodine intake, boys 6–11 years of age had the highest intake, and the upper confidence limit of the median was just slightly within the range of excessive intake (Fig. 6).

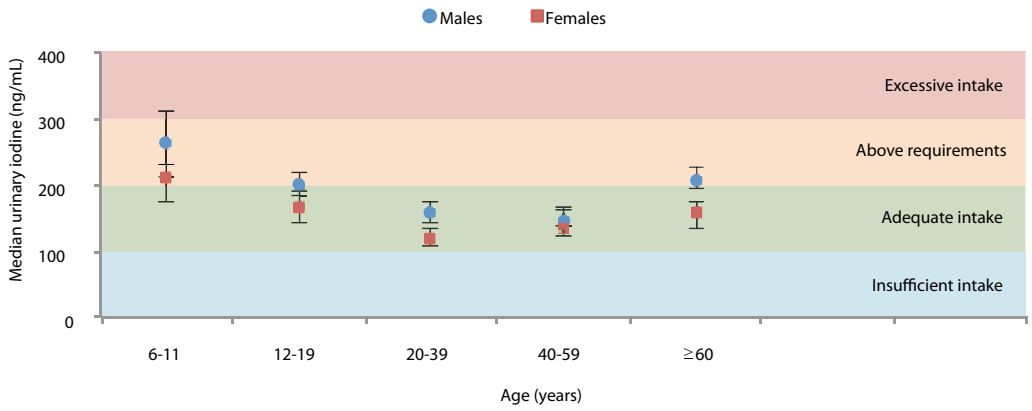


Figure 6. *Median levels of urine iodine in the U.S. population aged 6 years and older by age group and gender associated with estimated iodine intake, National Health and Nutrition Examination Survey, 2001–2006. Error bars represent 95% confidence intervals.*

First-time assessment of acrylamide exposure in the U.S. population

Acrylamide is a chemical naturally found in starchy foods that are cooked at high temperatures (above 120°C) and low-moisture conditions, such as those used for baking or frying. Foods that contain high acrylamide levels include potato chips, crackers, snacks, and coffee. Acrylamide is present in tobacco smoke, and it is an industrial chemical. In the body, some acrylamide is metabolized to glycidamide, which is an epoxide of acrylamide. Because glycidamide reacts with DNA, it is considered a genotoxic agent. Acrylamide has been categorized as *reasonably anticipated to be a human carcinogen*.

The lifelong exposure of most of the population to acrylamide through food and smoking has raised concerns about its potential health effects at low levels of intake. Measurement of acrylamide hemoglobin adduct levels provides information both about acrylamide exposure and metabolism.

The first-time acrylamide hemoglobin adduct levels in the U.S. population showed the following demographic patterns:

- Hemoglobin adduct levels were detectable in nearly all blood samples measured.
- We observed no consistent age, gender, or race/ethnicity patterns for the hemoglobin adduct levels.
- However, demographic differences emerged for the glycidamide-to-acrylamide hemoglobin adduct ratios.

Children had higher glycidamide-to-acrylamide hemoglobin adduct ratios compared to adolescents and adults, suggesting differences in acrylamide metabolism or metabolic rate among age groups[1]. Non-Hispanic blacks had lower hemoglobin adduct ratios compared to non-Hispanic whites and Mexican Americans, which may indicate differences in polymorphisms of the genes involved in phase II detoxification of acrylamide and glycidamide.[1]

More research is needed to better understand factors influencing acrylamide metabolism and the relationship between acrylamide exposure and health risks.

[1] Vesper HW, Caudill SP, Osterloh JD, et al. Exposure of the U.S. population to acrylamide in the National Health and Nutrition Examination Survey 2003–2004. Environ Health Perspect. 2010;118:278–283.

Plans for future *Nutrition Reports*

CDC's goal is to make new biochemical nutrition information available as soon as possible to the public and to the scientific community. To meet this goal, CDC periodically releases a new issue of the *Nutrition Report* and also publishes biochemical nutrition information in peer-reviewed publications. The *Nutrition Report* series provides biochemical nutrition information starting in 1999 through the latest available data at the time of the report release. Future plans include releasing data on additional indicators and providing more information on the nutrition status in population groups defined by age, sex, and race or ethnicity.

For the most up-to-date biochemical nutrition information, including the series of published reports as well as a list of peer-reviewed publications, users can view the *Nutrition Report* web site (http://www.cdc.gov/nutritionreport/).

About CDC's Nutritional Biomarkers Branch

The Nutritional Biomarkers Branch (NBB) develops and improves laboratory methods and analyzes essential nutrients (e.g., vitamins), nonessential nutrients (e.g., certain fatty acids), and dietary bioactive compounds (e.g., isoflavones and lignans) to evaluate nutrition status and its relationship to health. For many of these nutrients and dietary compounds, NBB produces population-based exposure levels segmented by age, sex, and race or ethnicity.

NBB reports nearly 100,000 test results every year for a wide range of nutrition biomarkers measured in NHANES and other studies. In collaboration with CDC colleagues, NBB also plays an active role in evaluating the worldwide burden of micronutrient deficiencies, such as deficiencies in folate, vitamin A, and iron. Billions of people around the world are affected by micronutrient deficiencies that may cause birth defects, learning disabilities, mental retardation, reduced immunity, blindness, poor work capacity, or premature death. The laboratory provides training and technical assistance on questions about laboratory analysis and field logistics in preparation for national nutrition surveys in countries such as Argentina, Dominican Republic, Iraq, Kenya, Laos, Malawi, Nicaragua, Oman, Papua New Guinea, South Africa, Ukraine, Uzbekistan, Yemen, and Zambia.



Diet-and-nutrition indicators in the *Second Nutrition Report**

Water-Soluble Vitamins and Related Biochemical Compounds

Folate (serum and red blood cell)
Vitamin B6*
Vitamin B12
Homocysteine
Methylmalonic acid
Vitamin C*

Trace Elements

Ferritin
Soluble transferrin receptor*
Body iron*
Iodine

Isoflavones and Lignans

Isoflavones

Genistein
Daidzein
Equol
O-Desmethylangolensin

Lignans

Enterodiol
Enterolactone

Acrylamide Hemoglobin Adducts*

Acrylamide
Glycidamide
Glycidamide-to-acrylamide ratio

Fat-Soluble Vitamins & Nutrients

Vitamins A and E and Carotenoids

Vitamin A
Retinyl palmitate*
Retinyl stearate*
Vitamin E
gamma-Tocopherol
alpha-Carotene
trans-*beta*-Carotene
cis-*beta*-Carotene*
beta-Cryptoxanthin
Lutein and zeaxanthin
trans-Lycopene
Total lycopene (*cis*- and *trans*-)*

Vitamin D

25-Hydroxyvitamin D

Fatty Acids*

Saturated

Myristic acid (14:0)
Palmitic acid (16:0)
Stearic acid (18:0)
Arachidic acid (20:0)
Docosanoic acid (22:0)
Lignoceric acid (24:0)

Monounsaturated

Myristoleic acid (14:1n-5)
Palmitoleic acid (16:1n-7)
cis-Vaccenic acid (18:1n-7)
Oleic acid (18:1n-9)
Eicosenoic acid (20:1n-9)
Docosenoic acid (22:1n-9)
Nervonic acid (24:1n-9)

Polyunsaturated

Linoleic acid (18:2n-6)
alpha-Linolenic acid (18:3n-3)
gamma-Linolenic acid (18:3n-6)
Eicosadienoic acid (20:2n-6)
homo-*gamma*-Linolenic acid (20:3n-6)
Arachidonic acid (20:4n-6)
Eicosapentaenoic acid (20:5n-3)
Docosatetraenoic acid (22:4n-6)
Docosapentaenoic-3 acid (22:5n-3)
Docosapentaenoic-6 acid (22:5n-6)
Docosahexaenoic acid (22:6n-3)

* Indicates NEW biochemical indicators or groups of indicators in the *Second Nutrition Report*