NIH Office of Dietary Supplements

Dietary Supplement Fact Sheet:

Iodine

Introduction

Iodine is a trace element that is naturally present in some foods, added to others, and available as a dietary supplement. Iodine is an essential component of the thyroid hormones thyroxine (T4) and triiodothyronine (T3). Thyroid hormones regulate many important biochemical reactions, including protein synthesis and enzymatic activity, and are critical determinants of metabolic activity [1,2]. They are also required for proper skeletal and central nervous system development in fetuses and infants [1].

Thyroid function is primarily regulated by thyroid-stimulating hormone (TSH), also known as thyrotropin. It is secreted by the pituitary gland to control thyroid hormone production and secretion, thereby protecting the body from hypothyroidism and hyperthyroidism [1]. TSH secretion increases thyroidal uptake of iodine and stimulates the synthesis and release of T3 and T4. In the absence of sufficient iodine, TSH levels remain elevated, leading to goiter, an enlargement of the thyroid gland that reflects the body's attempt to trap more iodine from the circulation and produce thyroid hormones.

Iodine may have other physiological functions in the body as well. For example, it appears to play a role in immune response and might have a beneficial effect on mammary dysplasia and fibrocystic breast disease [2].

The earth's soils contain varying amounts of iodine, which in turn affects the iodine content of crops. In some regions of the world, iodine-deficient soils are common, increasing the risk of iodine deficiency among people who consume foods primarily from those areas. Salt iodization programs, which many countries have implemented, have dramatically reduced the prevalence of iodine deficiency worldwide [2,3].

Iodine in food and iodized salt is present in several chemical forms including sodium and potassium salts, inorganic iodine (I_2), iodate, and iodide, the reduced form of iodine [4]. Iodine rarely occurs as the element, which is a gas, but rather as a salt; for this reason, it is referred to as iodide and not iodine. Iodide is quickly and almost completely absorbed in the stomach and duodenum. Iodate is reduced in the gastrointestinal tract and absorbed as iodide [2,5]. When iodide enters the circulation, the thyroid gland concentrates it in appropriate amounts for thyroid hormone synthesis and most of the remaining amount is excreted in the urine [2]. The iodine-replete healthy adult has about 15–20 mg of iodine, 70%–80% of which is contained in the thyroid [6].

Median urinary iodine concentrations of 100–199 mcg/L in children and adults, 150–249 mcg/L in pregnant women and >100 mcg/L in lactating women indicate iodine intakes are adequate [3]. Values lower than 100 mcg/L in children and non-pregnant adults indicate insufficient iodine intake, although iodine deficiency is not classified as severe until urinary iodine levels are lower than 20 mcg/L.

Recommended Intakes

Intake recommendations for iodine and other nutrients are provided in the Dietary Reference Intakes (DRIs) developed by the Food and Nutrition Board (FNB) at the Institute of Medicine of the National Academies (formerly National Academy of Sciences) [2]. DRI is the general term for a set of reference values used for planning and assessing nutrient intakes of healthy people. These values, which vary by age and gender [2], include:

- Recommended Dietary Allowance (RDA): average daily level of intake sufficient to meet the

nutrient requirements of nearly all (97%–98%) healthy individuals.
- Adequate Intake (AI): established when evidence is insufficient to develop an RDA and is set at a level assumed to ensure nutritional adequacy.
- Estimated Average Requirement (EAR): average daily level of intake estimated to meet the requirements of 50% of healthy individuals. It is usually used to assess the adequacy of nutrient intakes in populations but not individuals.
- Tolerable Upper Intake Level (UL): maximum daily intake unlikely to cause adverse health effects [2].

Table 1 lists the current RDAs for iodine [2]. For infants from birth to 12 months, the FNB established an AI for iodine that is equivalent to the mean intake of iodine in healthy, breastfed infants in the United States.

Table 1: Recommended Dietary Allowances (RDAs) for Iodine [2]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	110 mcg*	110 mcg*		
7–12 months	130 mcg*	130 mcg*		
1–3 years	90 mcg	90 mcg		
4–8 years	90 mcg	90 mcg		
9–13 years	120 mcg	120 mcg		
14–18 years	150 mcg	150 mcg	220 mcg	290 mcg
19+ years	150 mcg	150 mcg	220 mcg	290 mcg

* Adequate Intake (AI)

The World Health Organization (WHO), United Nations Children's Fund (UNICEF), and the International Council for the Control of Iodine Deficiency Disorders (ICCIDD) recommend a slightly higher iodine intake for pregnant women of 250 mcg per day [3,7].

Sources of Iodine

Food

Seaweed (such as kelp, nori, kombu, and wakame) is one of the best food sources of iodine, but it is highly variable in its content (Table 2) [5]. Other good sources include seafood, dairy products (partly due to the use of iodine feed supplements and iodophor sanitizing agents in the dairy industry [8]), grain products, and eggs. Dairy products, especially milk, and grain products are the major contributors of iodine to the American diet [9]. Iodine is also present in human breast milk [2,5] and infant formulas.

Fruits and vegetables contain iodine, but the amount varies depending on the iodine content of the soil, fertilizer use and irrigation practices [2]. Iodine concentrations in plant foods can range from as little as 10 mcg/kg to 1 mg/kg dry weight [5]. This variability in turn affects the iodine content of meat and animal products because it affects the iodine content of foods that the animals consume [10]. The iodine content of different seaweed species also varies greatly [11]. For these reasons, the values in Table 2 are approximate.

Table 2: Selected Food Sources of Iodine [10,11,12]

Food	Approximate Micrograms (mcg) per serving	Percent DV*
Seaweed, whole or sheet, 1 g	16 to 2,984	11% to 1,989%
Cod, baked, 3 ounces	99	66%
Yogurt, plain, low-fat, 1 cup	75	50%

Iodized salt, 1.5 g (approx. 1/4 teaspoon)	71	47%
Milk, reduced fat, 1 cup	56	37%
Fish sticks, 3 ounces	54	36%
Bread, white, enriched, 2 slices	45	30%
Fruit cocktail in heavy syrup, canned, 1/2 cup	42	28%
Shrimp, 3 ounces	35	23%
Ice cream, chocolate, 1/2 cup	30	20%
Macaroni, enriched, boiled, 1 cup	27	18%
Egg, 1 large	24	16%
Tuna, canned in oil, drained, 3 ounces	17	11%
Corn, cream style, canned, 1/2 cup	14	9%
Prunes, dried, 5 prunes	13	9%
Cheese, cheddar, 1 ounce	12	8%
Raisin bran cereal, 1 cup	11	7%
Lima beans, mature, boiled, 1/2 cup	8	5%
Apple juice, 1 cup	7	5%
Green peas, frozen, boiled, 1/2 cup	3	2%
Banana, 1 medium	3	2%

*DV = Daily Value. DVs were developed by the U.S. Food and Drug Administration (FDA) to help consumers compare the nutrient contents of products within the context of a total diet. The DV for iodine is 150 mcg for adults and children aged 4 and older. However, the FDA does not require food labels to list iodine content unless a food has been fortified with this nutrient. Foods providing 20% or more of the DV are considered to be high sources of a nutrient.

The U.S. Department of Agriculture's (USDA's) Nutrient Database Web site [13] lists the nutrient content of many foods, but this list does not currently include iodine.

Iodized Salt

More than 70 countries, including the United States and Canada, have salt iodization programs. As a result, approximately 70% of households worldwide use iodized salt, ranging from almost 90% of households in North and South America to less than 50% in Europe and the Eastern Mediterranean regions [3].

In the United States, salt manufacturers have been adding iodine to table salt since the 1920s, although it is still a voluntary program [12]. The U.S. Food and Drug Administration (FDA) has approved potassium iodide and cuprous iodide for salt iodization [14] while the WHO recommends the use of potassium iodate due to its greater stability, particularly in tropical climates [3]. According to its label, iodized salt in the United States contains 45 mcg iodine/g salt (between 1/8 and 1/4 teaspoon); measured salt samples have an average level of 47.5 mcg iodine/g salt [12]. However, the majority of salt intake in the United States comes from processed foods, and food manufacturers almost always use non-iodized salt in processed foods. If they do use iodized salt, they must list the salt as iodized in the ingredient list on the food label [8].

Dietary supplements

Many multivitamin/mineral supplements contain iodine in the forms of potassium iodide or sodium iodide. Dietary supplements of iodine or iodine-containing kelp (a seaweed) are also available. A small study found that potassium iodide is almost completely (96.4%) absorbed in humans [15].

Iodine Intakes and Status

Iodine Intakes

The Total Diet Study (TDS), an FDA monitoring program, provides estimated iodine intakes of the U.S. population [9]. Through the TDS program, foods that represent the average U.S. diet are purchased and analyzed for several components, including iodine. Based on analytical results from TDS food samples collected between 2003 and 2004, combined with food consumption estimates, average iodine intakes in the United States range from 138 to 353 mcg/day across all age and gender groups [9]. These intakes meet or exceed the EAR for all groups.

TDS data do not include iodine that people obtain from the discretionary use of iodized salt [16,17]. Because many U.S. households use iodized salt, TDS data likely underestimate the true iodine intake of most U.S. residents. Data from the National Health and Nutrition Examination Survey (NHANES) collected between 1999 and 2004 indicate that 28–29% of adults use iodine-containing dietary supplements [18]; this use also adds to the population's total iodine intake.

Iodine status of general U.S. population

Iodine status is typically assessed using urinary iodine measurements. Urinary iodine reflects dietary iodine intake directly because people excrete more than 90% of dietary iodine in the urine [4]. Spot urine iodine measurements are a useful indicator of iodine status within populations [19,20]. However, 24-hour urinary iodine or multiple spot urine measurements are more accurate for individuals [4]. For a population of school-aged children or non-pregnant adults to be iodine sufficient, median urinary iodine concentrations should be greater than 100 mcg/L and no more than 20% of the population should have values lower than 50 mcg/L [3].

Urinary iodine measurements from NHANES have been used since 1971 to monitor the iodine status of the U.S. population [21]. Since the inception of the NHANES monitoring program, urinary iodine measurements have shown that the general U.S. population is iodine sufficient. This is despite the fact that urinary iodine levels decreased by more than 50% between 1971–1974 and 1988–1994 [2,22]. Much of this decline was a result of decreased levels of iodine in milk due to the reduced use of iodine-containing feed supplements and iodophor sanitizing agents in the dairy industry [23], as well as the reduced use of iodate dough conditioners by commercial bakers. The use of erythrosine, an iodine-containing food dye commonly used in fruit-flavored breakfast cereals, also decreased during this time [23], though it is unclear to what extent this change actually affected urinary iodine levels because the bioavailability of iodine from erythrosine has been found to be low [24]. This sharp decline in urinary iodine levels caused some concern during the late 1990s that the iodine sufficiency of the U.S. population could be at risk if this trend continued [22].

More recent NHANES measurements indicate that urinary iodine levels have stabilized in the general U.S. population. During 2007–2008, NHANES participants aged 6 years and older had a median urinary iodine concentration of 164 mcg/L, and 8.8 ± 0.4% had concentrations lower than 50 mcg/L [25]. Among women of reproductive age, the median urinary iodine concentration in NHANES 2005–2008 was 133 mcg/L, and 14.6 ± 1.7% had concentrations lower than 50 mcg/L. These values have essentially remained unchanged in the last three NHANES surveys, indicating that the dietary iodine intake of the general U.S. population has remained stable since 2000 [25].

Iodine Status of U.S. Pregnant Women

According to the WHO, a median urinary iodine concentration of 150–249 mcg/L indicates adequate iodine nutrition during pregnancy, while values less than 150 mcg/L are considered insufficient [3,7]. Analyses of NHANES datasets covering time periods from 2001 to 2008 indicate that a substantial portion of pregnant women in the United States are iodine insufficient. Median urinary iodine concentrations for pregnant women participating in NHANES surveys were 181 mcg/L in 2003–2004 [21] and 153 mcg/L in 2001–2006 [26], and only 125 mcg/L in 2005–2008 [25]. Further, 56.9% of pregnant women surveyed during 2005–2008 had a median urinary iodine concentration <150 mcg/L [25]. In a study published in 2004, the median urinary iodine concentration of 100 healthy pregnant

women in Boston was 149 mcg/L and 49% of the women had values below the WHO cutoff for sufficiency [27]. The NHANES analyses and the Boston study each had relatively small sample sizes but they do raise concerns about the adequacy of iodine status of pregnant women in the United States. Suboptimal iodine status during pregnancy has also been observed in Australia [28].

Pregnant women who do not consume dairy products may be particularly at risk of iodine insufficiency. According to NHANES 2001–2006 data, pregnant women who consumed no dairy products in the previous 24 hours had a median urinary iodine concentration of only 100 mcg/L, compared with 163 mcg/L among consumers of dairy [26]. Women who restrict their dietary salt intake also have lower urinary iodine concentrations and might be more likely to be iodine deficient than women who don't restrict salt intake [29].

Overall, it appears that the general U.S. population has adequate iodine intake but that some pregnant women may be at risk for iodine deficiency. Continued national iodine monitoring is needed with more emphasis on population subgroups that are most susceptible to iodine deficiency disorders.

Iodine Deficiency

Iodine deficiency has multiple adverse effects on growth and development, and is the most common cause of preventable mental retardation in the world [30]. Iodine deficiency disorders result from inadequate thyroid hormone production secondary to insufficient iodine [5]. During pregnancy and early infancy, iodine deficiency can cause irreversible effects.

Under normal conditions, the body tightly controls thyroid hormone concentrations via TSH. Typically, TSH secretion increases when iodine intake falls below about 100 mcg/day [5]. TSH increases thyroidal iodine uptake from the blood and the production of thyroid hormone. However, very low iodine intakes can reduce thyroid hormone production even in the presence of elevated TSH levels.

If a person's iodine intake falls below approximately 10–20 mcg/day, hypothyroidism occurs [1], a condition that is frequently accompanied by goiter. Goiter is usually the earliest clinical sign of iodine deficiency [2]. In pregnant women, iodine deficiency of this magnitude can cause major neurodevelopmental deficits and growth retardation in the fetus, as well as miscarriage and stillbirth [5]. Chronic, severe iodine deficiency *in utero* causes cretinism, a condition characterized by mental retardation, deaf mutism, motor spasticity, stunted growth, delayed sexual maturation, and other physical and neurological abnormalities [5].

In infants and children, less severe iodine deficiency can also cause neurodevelopmental deficits such as somewhat lower-than-average intelligence as measured by IQ [1,31]. Mild to moderate maternal iodine deficiency has also been associated with an increased risk for attention deficit hyperactivity disorder in children [32]. In adults, mild-to-moderate iodine deficiency can cause goiter as well as impaired mental function and work productivity secondary to hypothyroidism. Chronic iodine deficiency may be associated with an increased risk of the follicular form of thyroid cancer [33].

Groups at Risk of Iodine Inadequacy

Historically, iodine deficiency was endemic in mountainous regions of the United States and Mexico, and in the so called "goiter belt" around the Great Lakes [34]. Thanks to a more national food supply, iodized salt and other factors, iodine deficiency is now uncommon in North America. Worldwide however, iodine deficiency remains a public health problem in 47 countries [6], and about 2.2 billion people (38% of the world's population) live in areas with iodine deficiency [30]. International efforts since the early 1990s have dramatically reduced the incidence of iodine deficiency, but some groups of people are still at risk of inadequate iodine intake.

People living in regions with iodine-deficient soils

Iodine-deficient soils produce crops that have low iodine levels. Mountainous areas, such as the Himalayas, Alps, and Andes regions, and river valleys prone to flooding, especially in South and Southeast Asia, are among the most iodine-deficient regions in the world [5]. Populations in these areas are at risk of iodine deficiency unless they have access to iodized salt or foods produced outside the iodine-deficient area.

People with marginal iodine status who eat foods containing goitrogens
Consumption of foods that contain goitrogens, substances that interfere with the uptake of iodine in the thyroid, can exacerbate iodine deficiency [2]. Foods high in goitrogens include soy and cassava, cabbage, broccoli, cauliflower, and other cruciferous vegetables. Deficiencies of iron and/or vitamin A may also be goitrogenic [35]. These issues are of concern primarily for people living in areas prone to iodine deficiency [6]. For most people, including most of the U.S. population, who have adequate iodine intakes and eat a variety of foods, the consumption of foods containing goitrogens in reasonable amounts is not a concern.

People who do not use iodized salt
The use of iodized salt is the most widely used strategy to control iodine deficiency. Currently, about 70% of households worldwide use iodized salt, but iodine insufficiency is still prevalent in certain regions. In the European region included in WHO reports, 52% of the population has insufficient iodine intake and, according to UNICEF, only about 49% of households in Europe (outside of the Western European subregion) have access to iodized salt. Iodine insufficiency is also prevalent in Africa, Southeast Asia, and the Eastern Mediterranean WHO regions where rates of iodized salt use range from approximately 47% to 67% [3,36]. Worldwide, it is estimated that about 31% of school-age children do not have access to iodized salt [37].

Pregnant women
During pregnancy, the RDA for iodine increases from 150 to 220 mcg/day [2]. Surveys indicate that many pregnant women in the United States, while not showing signs of overt iodine deficiency, may obtain insufficient amounts of iodine [25]. The impact of this, if any, on fetal development is not known at this time.

Iodine and Health

Due to its important role in fetal and infant development and thyroid hormone production, iodine is a critical nutrient for proper health at all life stages. This section focuses on four areas of biomedical research examining iodine's role in health and disease: fetal and infant development, cognitive function during childhood, fibrocystic breast disease, and radiation-induced thyroid cancer.

Fetal and infant development
Iodine sufficiency during pregnancy is extremely important for proper fetal development. During early pregnancy, when fetal thyroid gland development is incomplete, the fetus depends entirely on maternal T4 and therefore, on maternal iodine intake [38]. Production of T4 increases by approximately 50% during pregnancy [39], requiring a concomitant increase in maternal iodine intake. Sufficient iodine intake after birth is also important for proper physical and neurological growth and maturation.

Research suggests that infants are more sensitive to the effects of iodine deficiency than other age groups, as indicated by changes in their TSH and T4 levels in response to even mild iodine deficiency [40]. To accommodate increased iodine needs during pregnancy and lactation, the iodine RDA is 220 mcg/day for pregnant women and 290 mcg/day for lactating women [2]. Similarly, the WHO recommends 250 mcg/day during pregnancy and lactation [3].

Although severe iodine deficiency disorders are uncommon in the United States, mild-to-moderate iodine insufficiency during pregnancy may subtly affect fetal development [4,27,41]. In a 2009 study, researchers measured the neuropsychological status of Spanish infants whose mothers received daily

supplements of 300 mcg iodine (as potassium iodide) during pregnancy and lactation [42]. The mothers were moderately, but not severely, iodine deficient. Iodine supplementation resulted in significant improvements in some but not all aspects of neurodevelopment (as measured by Bayley Psychomotor Development scores) at 3–18 months of age compared with infants whose mothers did not receive iodine supplements.

Breast milk contains iodine, although concentrations vary based on maternal iodine levels. Infants who are exclusively breastfed depend on maternal iodine sufficiency for optimal development. In a study of 57 healthy lactating women from the Boston area, median breast milk iodine content was 155 mcg/L [43]. Based on reported infant iodine needs and the typical volume of breast milk consumed, the authors calculated that 47% of the women may have been providing their infants breast milk containing insufficient amounts of iodine. During the weaning period, infants not receiving iodine-containing complementary foods may also be at risk of iodine deficiency, even in countries with iodized salt programs [44].

To ensure that adequate amounts of iodine are available for proper fetal and infant development, several national and international groups recommend iodine supplementation during pregnancy, lactation, and early childhood. For women living in countries with weak, sporadic, or uneven iodized salt distribution, the WHO recommends iodine supplementation for all women of childbearing age to achieve a total iodine intake of 150 mcg/day. For pregnant and lactating women in these countries, iodine intakes of 250 mcg/day from both supplements and dietary sources are recommended [3,7]. WHO recommendations for these countries also include breastfeeding through 24 months of age, combined with complementary foods fortified with iodine for children between the ages of 7–24 months [7]. In the United States and Canada, the American Thyroid Association recommends iodine supplementation (150 mcg/day) as part of a prenatal vitamin/mineral supplement for pregnant and lactating women [45]. A National Research Council committee also recommends adding iodide to prenatal vitamins [1]. Currently, it is estimated that only 51% of the types of prenatal multivitamins marketed in the United States contain iodine [46] and according to 2001–2006 NHANES data, 15% of lactating women and 20% of non-pregnant and pregnant women in the United States take a supplement containing iodine [47].

Results from a 2010 study however, raise some questions as to the safety of widespread iodine supplementation in areas of relative iodine sufficiency. In this cross-sectional study, pregnant women living in Spain had a significantly increased risk of hyperthyrotropinemia (TSH >3 microU/mL) if they consumed iodine supplements in doses ≥200 mcg/day compared with those who consumed doses <100 mcg/day [48]. These findings suggest that taking higher doses of supplemental iodine during pregnancy could induce thyroid dysfunction in some women and underscore the need for additional research into the effects on maternal thyroid function of iodine supplementation during pregnancy.

Taken as a whole, these findings indicate that increased public awareness of iodine's importance during pregnancy and lactation is warranted and that further research into the effects of iodine supplementation during pregnancy is needed. Many researchers, as well as the American Thyroid Association, stress the importance of continued iodine status monitoring among women of reproductive age [1,4,21,26,40,41,45,49].

Cognitive function during childhood

The effects of severe iodine deficiency on neurological development are well documented. Results from several studies suggest, for example, that chronic, moderate-to-severe iodine deficiency, particularly in children, reduces IQ by about 12–13.5 points [39]. A 2004 Cochrane review concluded that iodine supplementation in children living in areas of iodine deficiency appears to both positively affect physical and mental development and decrease mortality with only minor and transient adverse effects [50].

The effects of mild iodine deficiency during childhood are more difficult to quantify. Some research suggests that mild iodine deficiency is associated with subtle neurodevelopmental deficits and that

iodine supplementation might improve cognitive function in mildly iodine-deficient children [38].

In a 2009 randomized, placebo-controlled study, 184 children aged 10–13 years in New Zealand with a median urinary iodine concentration of 63 mcg/L received iodine supplements (150 mcg/day) or placebo for 28 weeks [51]. Iodine supplementation improved iodine status (median urinary iodine concentration after supplementation was 145 mcg/L) and significantly improved measures of perceptual reasoning and overall cognitive score compared with children taking a placebo. These findings suggest that correcting mild iodine deficiency in children could improve certain components of cognition. Additional research is required to fully understand the effects of mild iodine deficiency and iodine supplementation on cognitive function.

Fibrocystic breast disease

Fibrocystic breast disease is a benign condition characterized by lumpy, painful breasts and palpable fibrosis. It commonly affects women of reproductive age, but it can also occur during menopause, especially in women taking estrogens [52]. Breast tissue has a high concentration of iodine, especially during pregnancy and lactation) [4,53]. Some research suggests that iodine supplementation might be helpful for fibrocystic breast disease, although a specific mechanism of action has not been established [54] and data are limited.

In a double-blind study, researchers randomly assigned 56 women with fibrocystic breast disease to receive daily supplements of iodine (70 to 90 mcg I_2/kg body weight) or placebo for 6 months [52]. At treatment completion, 65% of the women receiving iodine reported decreased pain compared with 33% of women in the placebo group. A more recent randomized, double-blind, placebo-controlled clinical trial had similar findings. In this study, researchers randomly assigned 111 women (18–50 years of age) with fibrosis and a history of breast pain to receive tablets containing 0 mcg, 1,500 mcg, 3,000 mcg, or 6,000 mcg of iodine per day [54]. After 5 months of treatment, women receiving doses of 3,000 or 6,000 mcg iodine had a significant decrease in breast pain, tenderness, and nodularity compared with those receiving placebo or 1,500 mcg iodine. The researchers also reported a dose-dependent reduction in self-assessed pain. None of the doses was associated with major adverse events or changes in thyroid function test results.

Although the results of these studies are promising, more research is needed to clarify iodine's role in fibrocystic breast disease. Moreover, the doses used in these studies (approximately 1,500–6,000 mcg per day) are several times higher than the iodine UL of 1,100 mcg for adults. Doses of this magnitude should only be used under the guidance of a physician [2].

Radiation-induced thyroid cancer

Nuclear accidents can release radioactive iodine into the environment, increasing the risk of thyroid cancer in exposed individuals, especially children [55,56]. Thyroidal uptake of radioactive iodine is higher in people with iodine deficiency than in people with iodine sufficiency. For this reason, iodine-deficient individuals have a particularly high risk of developing radiation-induced thyroid cancer when exposed to radioactive iodine.

The FDA has approved potassium iodide as a thyroid-blocking agent to reduce the risk of thyroid cancer in radiation emergencies involving the release of radioactive iodine [55]. The FDA recommends that exposed people take a daily pharmacological dose (16–130 mg potassium iodide, depending on age) until the risk of significant radiation exposure ends [55,56]. Potassium iodide was widely used in Poland following the 1986 Chernobyl accident and childhood thyroid cancer rates did not increase substantially in subsequent years [57]. In areas where iodide prophylaxis was not used, such as Belarus and Ukraine, where many children were mildly iodine-deficient, the incidence of thyroid cancer sharply increased among children and adolescents [55].

Health Risks from Excessive Iodine

High intakes of iodine can cause some of the same symptoms as iodine deficiency—including goiter, elevated TSH levels, and hypothyroidism—because excess iodine in susceptible individuals inhibits thyroid hormone synthesis and thereby increases TSH stimulation, which can produce goiter [2,58]. Iodine-induced hyperthyroidism can also result from high iodine intakes, usually when iodine is administered to treat iodine deficiency. Studies have also shown that excessive iodine intakes cause thyroiditis and thyroid papillary cancer [2,58]. Cases of acute iodine poisoning are rare and are usually caused by doses of many grams. Acute poisoning symptoms include burning of the mouth, throat, and stomach; fever; abdominal pain; nausea; vomiting; diarrhea; weak pulse; and coma [2].

Responses to excess iodine and the doses required to cause adverse effects vary [58]. Some people, such as those with autoimmune thyroid disease and iodine deficiency, may experience adverse effects with iodine intakes considered safe for the general population [2,5].

The FNB has established iodine ULs for food and supplement intakes (Table 3). In most people, iodine intakes from foods and supplements are unlikely to exceed the UL [2]. Long-term intakes above the UL increase the risk of adverse health effects. The ULs do not apply to individuals receiving iodine for medical treatment, but such individuals should be under the care of a physician [2].

Table 3: Tolerable Upper Intake Levels (ULs) for Iodine [2]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	Not possible to establish*	Not possible to establish*		
7–12 months	Not possible to establish*	Not possible to establish*		
1–3 years	200 mcg	200 mcg		
4–8 years	300 mcg	300 mcg		
9–13 years	600 mcg	600 mcg		
14–18 years	900 mcg	900 mcg	900 mcg	900 mcg
19+ years	1,100 mcg	1,100 mcg	1,100 mcg	1,100 mcg

* Formula and food should be the only sources of iodine for infants.

Interactions with Medications

Iodine supplements have the potential to interact with several types of medications. A few examples are provided below. Individuals taking these medications on a regular basis should discuss their iodine intakes with their health care providers.

Anti-thyroid medications
Anti-thyroid medications, such as methimazole (Tapazole®), are used to treat hyperthyroidism. Taking high doses of iodine with anti-thyroid medications can have an additive effect [59] and could cause hypothyroidism.

Angiotensin-converting enzyme (ACE) inhibitors
Angiotensin-converting enzyme (ACE) inhibitors, such as benazepril (Lotensin®), lisinopril (Prinivil® and Zestril®), and fosinopril (Monopril®), are used primarily to treat high blood pressure. Taking potassium iodide with ACE inhibitors can increase the risk of hyperkalemia (elevated blood levels of potassium) [59].

Potassium-sparing diuretics
Taking potassium iodide with potassium-sparing diuretics, such as spironolactone (Aldactone®) and amiloride (Midamor®), can increase the risk of hyperkalemia [59].

Iodine and Healthful Diets

The federal government's 2010 *Dietary Guidelines for Americans* notes that "nutrients should come

primarily from foods. Foods in nutrient-dense, mostly intact forms contain not only the essential vitamins and minerals that are often contained in nutrient supplements, but also dietary fiber and other naturally occurring substances that may have positive health effects. ...Dietary supplements...may be advantageous in specific situations to increase intake of a specific vitamin or mineral."

For more information about building a healthful diet, refer to the *Dietary Guidelines for Americans* and the U.S. Department of Agriculture's food guidance system, MyPlate.

The *Dietary Guidelines for Americans* describes a healthy diet as one that:

- Emphasizes a variety of fruits, vegetables, whole grains, and fat-free or low-fat milk and milk products.
  Milk is an excellent source of iodine. Fruits, vegetables, and bread also provide small quantities of iodine.
- Includes lean meats, poultry, fish, beans, eggs, and nuts.
  Some fish contain high amounts of iodine. Eggs are also good sources of iodine.
- Is low in saturated fats, *trans* fats, cholesterol, salt (sodium), and added sugars.
- Stays within your daily calorie needs.

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