0021-972X/04/$15.00/0
Printed in U.S.A.

The Journal of Clinical Endocrinology & Metabolism 89(7):3421–3424

doi: 10.1210/jc.2003-032002

COMMENT

Sources of dietary Iodine: Bread, Cows' Milk, and Infant Formula in the Boston Area.

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Dietary iodine is essential for thyroid hormone production. Although U.S. dietary iodine is generally adequate, some groups, especially women of childbearing age, are at risk for mild iodine deficiency. Children's average urinary iodine is higher than that of adults. U.S. dietary iodine sources have not been assessed recently. A survey of iodine content in 20 brands of bread, 18 brands of cows' milk, and eight infant formulae was performed between 2001 and 2002. Three bread varieties contained more than 300 μg iodine per slice. Iodine content in other brands was far lower (mean ± SD, 10.1 ± 13.2 μg iodine/slice). All cows' milk samples had at least 88 μg iodine/250 ml, ranging from 88–168 μg (116.0 ± 22.1 μg/250 ml). Infant formulae values ranged from 16.2 to 56.8 μg iodine/5 oz (23.5 ± 13.78 μg/5 oz). The public should be aware of the need for adequate dietary iodine intake and should be aware that ingredient lists do not reflect the iodine content of foods. (*J Clin Endocrinol Metab* 89: 3421–3424, 2004)

ADEQUATE DIETARY IODINE intake is essential for the production of thyroid hormones. The recommended daily allowances for iodine vary by age (Table 1) (1). Iodine intake in the United States has varied over the years due to alterations in the iodine content of foodstuffs. Since the iodization of salt and other foods in the 1920s, U.S. dietary iodine has generally been adequate. Subjects sampled for the most recent U.S. National Health and Nutrition Examination Survey (NHANES 2000) had a median urinary iodine excretion of 16.1 μg/dl (National Center for Health Statistics: Health E-Stats: Iodine Level, United States, 2000; http://www.cdc.gov/nchs/products/pubs/pubd/hestats/iodine.htm), which was essentially unchanged from the previous survey in 1988–1994 (NHANES III) (2). However, NHANES III demonstrated an approximate 50% reduction in median dietary iodine intake (median urinary iodine, 14.5 μg/dl) compared with NHANES I values from 1971–1974 (median urinary iodine, 32.0 μg/dl) (2). In particular, some subsets of the population, especially women of childbearing age, had an increased prevalence of mild iodine deficiency. This is of concern because thyroid hormone, requiring adequate iodine intake, is critical for neural development *in utero* and in early life. Although cretinism due to iodine deficiency is not a problem in the United States, subtle developmental delays could result from mild maternal iodine deficiency. Another population subset, school-aged children, had urinary iodine excretion in both the NHANES I and III surveys that was higher than that of adults (2).

In the United States, iodine deficiency has been largely eliminated by means of silent prophylaxis. Iodine supplementation of salt and other foods has never been mandated, and iodine content of most foods is not listed on package labels. It has been over 10 yr since the last market basket analysis for U.S. iodine intake was performed (3). Therefore, it has been difficult to determine the primary sources of iodine in the U.S. diet. In particular, the higher median urinary iodine levels in children compared with adults, reflecting dietary iodine intake, have not been explained.

Materials and Methods

To document some potentially important sources of iodine in the U.S. diet, we measured iodine content in a variety of locally available dietary staples during 2001–2002.

Two slices of bread were obtained from 20 different brands of sliced bread from supermarkets in the Boston area. An initial sample of breads was brought from home by co-workers; several more brands were then selected randomly at a local supermarket. Iodine content was analyzed in 100–150 mg of each slice and measured in duplicate. Seven brands, all products of the Interstate Bakeries Corp. (Charlotte, NC), listed iodate conditioners as ingredients; the iodine content was not indicated. None of the store-bought breads listed iodized salt as an ingredient. When some of the brands that listed iodate conditioners in the ingredients list were tested, the samples contained only small amounts of iodine. The manufacturer was contacted and indicated that the iodine conditioners had been removed from all the breads at the last recipe reformulation and that supplies of the old bread bags were being depleted.

The iodine content of 18 brands of milk sold in local supermarkets was measured. Because cows' milk from some processing plants is sold under multiple brand names, we effectively measured milk from five separate sources. Measurements were performed twice on each brand, once in February and once in August, to determine whether there was any seasonal variation in milk iodine content. Milk iodine content was

Abbreviation: NHANES, National Health and Nutrition Examination Survey.

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not included on any of the labels. The iodine content of eight infant formulae, representing all types available at a single large local supermarket, was also measured and compared with their labeled iodine content.

Total iodine concentrations in cows' milk, infant formulae, and bread were measured spectrophotometrically by a modification of the method of Benotti *et al.* (4). All samples were digested with 3.0 ml chloric acid (30% aqueous solution) before analysis. Iodine concentrations from all samples were measured at least twice; in 95% of the samples, the initial two measurements were within 15% of each other, and the two values were averaged. In cases where the initial two measurements were not within 15% of each other, a third or a fourth measurement was obtained, and the average of all measurements was reported.

Statistical analyses were performed using SAS version 8 (SAS Institute, Cary, NC). Paired *t* tests were used to compare mean iodine content in winter compared with summer cows' milk samples.

TABLE 1. United States Institute of Medicine recommendations for iodine intake

Group	Iodine intake (μg/d)
Age 0–6 months	110 (AI)[a]
Age 7–12 months	130 (AI)
Age 1–8 yr	90 (RDA)[a]
Age 9–13 yr	120 (RDA)
Age 14 yr and over	150 (RDA)
Pregnant women	220 (RDA)
Lactating women	290 (RDA)

AI, Adequate intake; RDA, recommended daily allowance.

[a] The RDA is the intake of a nutrient expected to meet the needs of 97–98% of healthy individuals. The AI is an approximation of the dietary intake of healthy people who are assumed to be getting adequate nutrition. The AI is used when there is not enough evidence to determine the RDA; it always exceeds the RDA.

Results

Three varieties of bread contained more than 313 μg iodine per slice (range, 313.5–587.4 μg). Iodine content in the other 17 brands ranged from 2.2–54 μg iodine per slice (mean, 10.1 ± 13.2 μg iodine/slice; Table 2).

All 18 brands of cows' milk had at least 88 μg iodine per 250 ml (~8 oz or 1 cup), ranging from 88–168 μg (mean ± SD, 116.0 ± 22.1 μg/250 ml; Fig. 1). Mean iodine content of

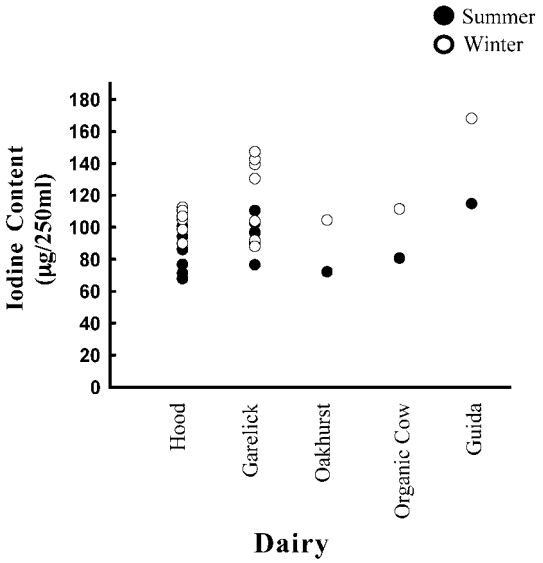

FIG. 1. Iodine concentrations in summer and winter cows' milk samples by source dairy.

TABLE 2. Iodine concentration in breads from the Boston area

Bread brand	Weight per slice (g)	Iodine (μg/g)	Total iodine per slice (μg)
Arnold Jewish Bread[a]	31.5	0.11	3.5
Bouyea Fassett 12 Grain Bread[a]	47.4	0.10	4.6
Cape Cod Wheat Bread	33.6	0.35	11.8
Country Kitchen Butter Split Wheat[b]	28.4	0.09	2.6
Country Kitchen Giant White[b]	30.0	0.13	3.8
Country Kitchen Hearty Canadian Brown[b]	34.4	0.09	3.2
Finagle a Bagel Rye Bagel[c]	132.1	0.11	13.9
Home Pride Butter Top Wheat[d]	29.0	0.19	5.4
Home Pride Butter Top White[d]	30.6	0.21	6.5
J.J. Nissen Italian[d]	28.2	0.11	3.1
J.J. Nissen Split Top Wheat[d]	30.0	0.19	5.7
Martin's Potato Bread[e]	33.9	0.49	16.6
Pepperidge Whole Grain[f]	29.0	0.12	3.5
Shaw's Foccacia[g]	25.2	23.31	587.4
Shaw's Giant White[g]	25.8	1.13	29.2
Shaw's Marble Rye[g]	25.3	2.12	53.5
Sunbeam Batter Whipped White[d]	26.3	12.49	328.0
Sunbeam White[d]	26.7	12.15	324.3
When Pigs Fly Six Grain and Pumpkin Seed[h]	51.2	0.06	2.8
Wonder Bread[d]	25.4	0.09	2.2

[a] Products of George Weston Bakeries, Inc. (Totowa, NJ).
[b] Products of LePage Bakeries (Auburn, ME).
[c] Product of Finagle a Bagel (Boston, MA).
[d] Products of the Interstate Bakeries Corp. (Charlotte, NC).
[e] Product of Martin's Famous Pastry Shoppe, Inc. (Chambersburg, PA).
[f] Product of Campbell Soup Co. (Camden, NJ).
[g] Products of Shaw's Supermarkets, Inc. (West Bridgewater, MA).
[h] Product of When Pigs Fly, Inc. (York, ME).

cows' milk was significantly higher in the winter (116 ± 23.1 μg/250 ml) than in the summer (91.3 ± 16.6 μg/250 ml, $P = 0.0004$). Values for infant formulae ranged from 16.2–56.8 μg iodine per 5 oz serving (mean, 23.5 ± 13.78 μg/5 oz), which was often far higher than labeled (Table 3).

Discussion

Recent reductions in U.S. dietary iodine intake have been ascribed to a possible reduction in iodine content in dairy products, to the removal of iodate conditioners in store-bought breads, to new recommendations for reduced salt intake for blood pressure control, and to the increasing use of noniodized salt in manufactured or pre-made convenience foods (3, 5).

Inadequate dietary iodine is a significant worldwide health problem. Disorders caused by inadequate dietary iodine include goiter, subclinical or overt hypothyroidism, mental retardation, decreased fertility, increased neonatal mortality, and cretinism (6–8). Adequate iodine is particularly important for neural development *in utero* and in early life (9), and iodine deficiency remains the leading preventable cause of mental retardation worldwide (6). Furthermore, iodine deficiency will result in increased uptake of radioactive iodine and could, at least partially, explain the high prevalence of childhood thyroid cancer after the Chernobyl accident (10). Although chronic ingestion of excess iodine generally does not represent a significant public health problem, it may result in hypo- or hyperthyroidism in susceptible individuals, especially those with Hashimoto's thyroiditis and nodular nontoxic goiter, respectively. Excess iodine ingestion will also decrease the thyroid radioactive iodine uptake and reduce the effectiveness of radioactive iodine treatment for thyrotoxicosis and differentiated thyroid cancer.

Assessment of U.S. dietary iodine sources has not been performed for several years. Kidd *et al.* (11) obtained dietary frequency surveys and urinary iodine measurements from a sample of 754 schoolchildren between 1971 and 1972. Bread made with iodate conditioners, milk, and iodized salt were the primary sources of dietary iodine in their sample. National market basket samples performed for the Food and Drug Administration's Total Diet Study between 1982 and 1991 estimated that the average diet at the time contained iodine levels in excess of the current recommended daily allowance (3, 12).

Conditioners are added to store-bought bread to maintain freshness and prolong shelf life. In the 1960s, iodate bread conditioners were widely used. London *et al.* (13), in 1965, reported that bread was a source of large quantities of dietary iodine, with iodine content as high as 150 μg per slice. This was considered to be a contributing cause to the decreasing radioactive iodine uptake in the U.S. during the 1960s (14, 15). Because of the concerns about high bread iodine content, commercial bakeries now less commonly use iodate bread conditioners. The decreasing use of iodate bread conditioners is thought to have contributed to the reduction in dietary iodine levels between the 1970s and the early 1990s.

Three brands of bread in our study had inordinately high iodine content, up to 587 μg iodine per slice, which was likely due to the presence of iodate bread conditioners. Thus, if an individual eats two slices of these breads over a 24-h period, up to 1,174 μg iodine will be ingested from bread alone, resulting in excess iodine exposure assuming an otherwise normal diet. The tolerable upper limit for daily iodine intake in adults established by the U.S. Institute of Medicine is 1,100 μg (1). The ingredient list for only one of these breads indicated the use of an iodate conditioner. By contrast, the iodine content of several bread brands was low despite ingredient labeling that indicated use of iodate. It is clear that current labeling of bread does not accurately predict the content of iodine. Bread manufacturers should be encouraged to avoid the addition of additives containing excess iodine and to accurately list all iodine-containing substances and the iodine content per bread slice on an easily readable label.

Cows' milk continues to be a primary source of U.S. dietary iodine. Milk iodine content increased by 300–500% over the period from 1965–1980, largely due to changes in cattle feeds (16). The limitation of the allowable amount of organic iodine ethylenediamine dihydroiodine in cattle feed to 10 mg per cow daily in 1986 has resulted in decreases in the iodine content of U.S. cows' milk. Iodine supplementation of cattle feed may contribute to the iodine content of cows' milk in New England, but unlike seasonal variations in milk iodine content in the United Kingdom (17), the seasonal variation in iodine content of cows' milk noted in this study cannot be ascribed to alterations in the diet of dairy cows (Hines, J. G., Director, Commonwealth of Massachusetts Department of Food and Agriculture Division of Diary Services, personal communication, January 2003). Iodine is also introduced into cows' milk by the use of iodophor disinfectant in pre- and postmilking teat dips and udder washes. Such teat dips contain up to 1% available iodine and have been shown to significantly increase milk iodine residues by absorption through the skin and subsequent incorporation into milk (18, 19). Povidone iodine disinfecting solutions are also used to clean tanker trucks, vats, and milking equipment; however, by Food and Drug Administration regulations, such solutions may contain only 12.5–25 parts iodine per million (20), and residues from these solutions are unlikely to add a substantial amount of iodine to the milk supply (Hines, J. G., personal communication). The average iodine content of milk in our sample was 110 μg per cup. The recommended intake for adequate calcium nutrition of 4 cups daily would provide 440 μg iodine daily. This intake is 4.8 times the recommended intake for children and 2.9 times

TABLE 3. Iodine content of infant formulae

Formula brand	Labeled iodine content (μg/5 oz)	Actual iodine content (μg/5 oz)
Enfamil with Iron[a]	10	17.9
Enfamil LactoFree[a]	15	22.2
Enfamil Nutramigen[a]	15	17.9
Enfamil ProSobee Soy Formula[a]	15	17.3
Nestle Carnation Follow Up[b]	8	56.8
Nestle Carnation Good Start[b]	8	16.2
Similac with Iron[c]	6	24.2
Similac Isomil Soy Formula[c]	15	15.9

[a] Products of Mead Johnson Nutritionals (Evansville, IN).
[b] Products of Nestle USA, Inc. (Glendale, CA).
[c] Products of Ross Products (Columbus, OH).

the recommended intake for adults. A combination of 4 cups of milk and two slices of bread could result in a daily ingestion of greater than 1,700 μg iodine, or 11.3 times the recommendations and 600 μg above adult tolerable limits. Generally, excess iodine intake is not a risk for thyroid dysfunction in the normal thyroids of children, but hypothyroidism or hyperthyroidism may occur in adults with preexisting Hashimoto's thyroiditis or nodular goiter, respectively. In view of the high iodine content in milk, it seems advisable that the iodine content should be incorporated into package labeling. Finally, infant formulae contain sufficient iodine, often more than labeled. They should provide infants with adequate iodine intake during this critical period of brain development.

Dietary iodine deficiency is an important public health problem worldwide. Overall, our findings, although based on small and nonrandom samples, suggest that U.S. iodine nutrition may remain an area worthy of public health concern. It is clear that there is a wide amount of variation in the iodine content of some common foods. Iodine content of foods is not well reflected by package labeling. There needs to be increased awareness of the importance of adequate iodine nutrition, particularly during pregnancy and lactation, among the U.S. public. Accurately identifying iodine content on food package labels would facilitate this process. Women of childbearing age should be encouraged to use iodine-containing multivitamins. Currently, many prenatal vitamins and other multivitamin preparations do not contain iodine (21). Salt iodization has been the mainstay of iodine deficiency prevention programs in countries around the world, and use of iodized salt should continue to be promoted in the United States. Finally, there is a need for larger and more systematic studies of iodine nutrition in different U.S. populations and for routine monitoring of food iodine content.

Acknowledgments

Received November 19, 2003. Accepted March 29, 2004.

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