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SPECIAL ARTICLE

Global Iodine Nutrition: Where Do We Stand in 2013?

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Background: Dietary iodine intake is required for the production of thyroid hormone. Consequences of iodine deficiency include goiter, intellectual impairments, growth retardation, neonatal hypothyroidism, and increased pregnancy loss and infant mortality.
Summary: In 1990, the United Nations World Summit for Children established the goal of eliminating iodine deficiency worldwide. Considerable progress has since been achieved, largely through programs of universal salt iodization. Approximately 70% of all households worldwide currently have access to adequately iodized salt. In 2013, as defined by a national or subnational median urinary iodine concentration of 100–299 μg/L in school-aged children, 111 countries have sufficient iodine intake. Thirty countries remain iodine-deficient; 9 are moderately deficient, 21 are mildly deficient, and none are currently considered severely iodine-deficient. Ten countries have excessive iodine intake. In North America, both the United States and Canada are generally iodine-sufficient, although recent data suggest pregnant U.S. women are mildly iodine-deficient. Emerging issues include discrepancies between urinary iodine status in pregnant women compared to school-aged children in some populations, the problem of re-emerging iodine deficiency in parts of the developed world, the importance of food industry use of iodized salt, regions of iodine excess, and the potential effects of initiatives to lower population sodium consumption on iodine intake.
Conclusions: Although substantial progress has been made over the last several decades, iodine deficiency remains a significant health problem worldwide and affects both industrialized and developing nations. The ongoing monitoring of population iodine status remains crucially important, and particular attention may need to be paid to monitoring the status of vulnerable populations, such as pregnant women and infants. There is also need for ongoing monitoring of iodized salt and other dietary iodine sources in order to prevent excess as well as insufficient iodine nutrition. Finally, it will be essential to coordinate interventions designed to reduce population sodium intake with salt iodization programs in order to maintain adequate levels of iodine nutrition as salt intake declines.

Introduction

Dietary iodine intake is required for the production of thyroid hormone. Consequences of iodine deficiency include endemic goiter, cretinism, intellectual impairments, growth retardation, neonatal hypothyroidism, and increased pregnancy loss and infant mortality (1). Thyroid hormone is particularly crucial for fetal and infant neurodevelopment *in utero* and in early life, and insufficient iodine during pregnancy and infancy results in neurological and psychological deficits in children (2). The intelligence quotient (IQ) of children living in severely iodine-deficient areas is, on average, 12 points lower than those living in iodine-sufficient areas, and IQ improves with iodine supplementation (3). Iodine deficiency remains the leading cause of preventable mental retardation worldwide (4). In adults, mild-to-moderate iodine deficiency increases the incidence of hyperthyroidism due to toxic goiter (5).

Excessive, as well as deficient, iodine intake can cause alterations in thyroid function, although most individuals tolerate high dietary intakes of iodine remarkably well, and intakes up to 1100 μg/day are considered safe in healthy adults (6). Following exposure to high iodine levels, the synthesis of thyroid hormone is normally inhibited via the acute Wolff–Chaikoff effect (7). If excessive iodine exposure persists, the thyroid is able to "escape" from the acute Wolff–Chaikoff effect within a few days (8). This is accomplished, in part, by downregulating NIS on the basolateral membrane, modulating the influx of iodine entering the thyroid (9). The Jod–Basedow phenomenon, or iodine-induced hyperthyroidism,

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occurs most commonly in individuals with a history of nontoxic diffuse or nodular goiters, which are more frequent in areas of iodine deficiency. Increases in rates of hyperthyroidism have been reported in historically iodine-deficient regions with the initiation of salt iodization, but this increase is typically transient, and incidence rates fall after sustained iodization to rates lower than before introduction of iodized salt (10). Conversely, individuals with subtle defects in thyroid hormone synthesis, such as those with Hashimoto's thyroiditis, may be unable to escape from the acute Wolff–Chaikoff effect, and can develop iodine-induced hypothyroidism. In addition, even small increases in population iodine intake are associated with an increased prevalence of thyroid autoimmunity (11).

There are several accepted methods for the monitoring of population iodine status (12). Because 90% of ingested iodine is renaly excreted, median spot urinary iodine concentrations (UIC) serve as a biomarker for recent dietary iodine intake. Median thresholds for median urinary iodine sufficiency from spot samples have been identified for populations, but these should not be applied to individuals because of significant day-to-day variation in salt intake, the main source of dietary iodine in many countries (13). Because of this variation, ~10 repeat spot urine collections are needed to estimate individual iodine intakes with acceptable precision (14,15). Population iodine sufficiency is defined by median urinary iodine concentrations of 100–299 μg/L in school-aged children, and ≥150 μg/L in pregnant women (16,17). Surveys of urinary iodine concentrations are most frequently carried out in populations of school-aged children, since they are convenient to sample and have been assumed to have iodine intakes characteristic of general populations.

In nearly all countries, the best strategy to control iodine deficiency is the addition of iodine to salt; it is simple, effective, safe, and inexpensive. Worldwide, nearly 70% of households in low-income countries have access to iodized salt and the annual costs of salt iodization are estimated at only US$0.02–0.05 per child (18,19). Household access to adequately iodized salt has also been used as a proxy for population iodine status, particularly in developing countries. Salt is considered to be adequately iodized when it contains 15–40 ppm iodine (16).

This review focuses on the current global iodine status and the current status of iodine nutrition in North America. In addition, some emerging issues are discussed, including discrepancies between urinary iodine status in pregnant women compared to school-aged children, the problem of re-emerging iodine deficiency in parts of the developed world, the importance of the use of iodized salt by the food industry, regions of iodine excess, and the potential effects of initiatives to lower population sodium consumption on iodine intake.

Discussion

Global iodine status in 2013

In 1990, the United Nations World Summit for Children established the goal of eliminating iodine deficiency worldwide (20). Considerable progress has since been achieved, largely through programs of universal salt iodization (USI), in line with the recommendations by the World Health Organization (WHO) and the International Council for the Control of Iodine Deficiency Disorders (ICCIDD) (16).

Data regarding household coverage with iodized salt are available for 128 UNICEF member states, of which 37 countries have achieved adequate iodized salt consumption in ≥90% of households, 52 have coverage in 50–89% of households, and 39 countries still have coverage in <50% of households. Overall, ~70% of all households worldwide currently have access to adequately iodized salt (18,21). This represents a substantial improvement from <10% of household coverage in 1990 (22). However, progress over the last decade has slowed, limited primarily by the technical challenges of reaching small salt producers, poor quality control of salt iodization, waning interest by governments, and by difficulties in enforcing iodized salt legislation.

There are currently UIC data available globally, which together represent 97.7% of the world population of school-aged children. Since the last global estimate in 2011 (23), new data are available for 15 countries, including, among others, Belgium, Benin, North Korea, Latvia, Thailand, and Zambia. Nationally representative surveys conducted between 1993 and 2012 are available for 119 countries. For 33 countries which lack national data, subnational UIC surveys were used. There are currently no UIC data available for 42 countries. Although the majority of the countries without data have small populations, larger countries without adequate UIC survey data include Israel, Syria, and Sierra Leone.

Currently, 111 countries have adequate iodine nutrition (Fig. 1). Thirty countries remain iodine-deficient, 9 are moderately deficient, 21 are mildly deficient, and none are currently considered severely iodine-deficient. Ten countries have excessive iodine intake. It is important to note that in countries classified overall as iodine-sufficient, some subgroups such as vegans or vegetarians (24), weaning infants (25), and those who do not use iodized salt due to choice or lack of access may still be deficient.

Between 2003 and 2013, the total number of countries with adequate iodine intake increased from 67 to 111 (26). Since the last global estimate in 2011 (23), the iodine status in Australia, Belgium, Latvia, and Mauritania improved from deficient to sufficient. In Finland, the iodine status deteriorated from sufficient to deficient, and in North Korea, the first national iodine survey reports mild iodine deficiency. In Benin, the iodine intake increased and is now excessive. Overall, there has been steady progress in Europe, the eastern Mediterranean, southeast Asia, and the western Pacific regions over the past 10 years, largely due to strengthened salt iodization programs and improved monitoring (18). However, there has been minimal recent progress in Africa.

North American iodine status in 2013

Since the 1920s, U.S. dietary iodine has been considered adequate. Based on the most recent U.S. 2003–2004 Food and Drug Administration's Total Diet Study, the estimated average daily iodine intake ranges from 138 to 353 μg/person (27). Based on National Health and Nutrition Examination Surveys (NHANES), the median UIC in U.S. adults decreased by >50% between the early 1970s and the late 1990s (28). Of particular concern, the prevalence of UICs <50 μg/L among women of childbearing age increased by almost fourfold, from 4% to 15%, over this period. The most recent NHANES survey (2009–2010) demonstrated that the overall

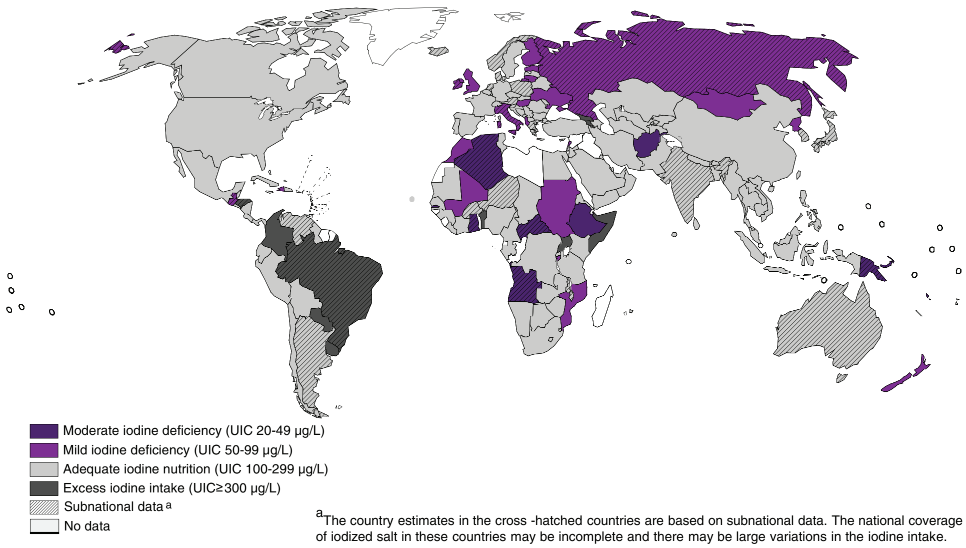

FIG. 1. National iodine status based on median urinary iodine concentrations in school-age children.

U.S. population remains iodine-sufficient, with a median UIC of 144 μg/L among individuals aged six years and older (29). However, aggregate NHANES data from 2001 to 2006 showed that U.S. pregnant women sampled were only marginally iodine-sufficient (median UIC, 153 μg/L) (30) and the most recent NHANES data from 2007 to 2010 demonstrated that the median UIC among pregnant U.S. women had dropped to $<150\,\mu$g/L, indicating mild iodine deficiency (31).

In the United States, sources of dietary iodine include iodized salt (due to the voluntary addition of iodine to table salt as a public health measure), dairy foods (due to the use of iodophor cleansers and livestock iodine supplements by the dairy industry), and some commercially-baked breads (due to the use of iodate as bread conditioners) (32). Reductions in U.S. dietary iodine over the last several decades have been variously ascribed to a possible reduction in the iodine content of dairy products, the removal of iodate dough conditioners in commercially produced bread, new recommendations for reduced salt intake for blood-pressure control, and the increasing use of noniodized salt by the food industry (33).

Iodine status in Canada has recently been assessed in a national survey and found to be adequate, with a median UIC of 134 μg/L (34). A recent cross-sectional study found a median UIC of 221 μg/L among 142 pregnant women from the Toronto area (35), but national surveys of iodine status in pregnancy have not been performed in Canada.

Emerging issues

Discrepancies between iodine status in school children and pregnant women. Pregnant women and their offspring are particularly vulnerable to the effects of iodine deficiency. However, few countries have completed national UIC surveys in pregnant women and women of reproductive age. This represents an important limitation of current global estimates of iodine status. Although the median UIC in school-aged children is typically used to represent the iodine status of most of the population, recent studies suggest that it may not be an appropriate proxy for iodine status in pregnant women (36,37). In populations where a substantial proportion of the total iodine intake comes from dairy sources (such as the United States), UIC in school-aged children, who usually consume the largest amounts of milk, may overestimate the iodine status of adults (29). This may be less of an issue in countries where salt is the primary source of iodine in the diet. However, it is likely that there will be an increased emphasis in the future on monitoring the iodine status of vulnerable populations.

Re-emerging iodine deficiency in industrialized countries. Although nutritional deficiencies are thought of as primarily a problem of developing countries, iodine deficiency affects industrialized countries as well as the developing world, and has reappeared in some regions that were previously iodine-sufficient. Iodine deficiency was endemic in parts of the United Kingdom until, through what has been described as "an unplanned and accidental public health triumph" (38), iodine was added to cattle feed to improve milk production in the 1930s. This resulted in increased iodine concentrations in cow milk and ensured adequate iodine nutrition in the United Kingdom despite the fact that $<5\%$ of salt sold in the United Kingdom is iodized (39). However, recent studies have suggested that vulnerable United Kingdom populations might again be iodine-deficient (40–43). Iodine deficiency appears to have re-emerged due to a decrease in United Kingdom milk consumption (44).

A similar process has occurred in Australia in recent years**.** Australia has very limited salt iodization. For decades, dietary iodine was provided mainly by the use of iodophor udder cleansers in the dairy industry—a fact that was only fully recognized when dairy practices changed in the 1990s and the country became iodine-deficient (45). In 2009, Australia and New Zealand mandated the iodization of salt in commercially-baked bread to ensure adequate iodine nutrition for their populations (46). Recent data from Sydney and Tasmania indicate increasing iodine intakes, likely as a result of the national iodine intervention program (47,48). Similarly, Denmark and Belgium now control iodine deficiency in their populations through iodization of salt used in bread making (49,50).

Regions of iodine excess. Based on the most recent national surveys, 10 countries are classified as having excessive iodine intakes (median UIC >300 μg/L) (16). Excess iodine intakes from iodized salt occur when the level of iodine added to salt is too high considering *per capita* salt intakes; the recommended fortification level is 20–40 ppm iodine in salt (16). These data emphasize the importance of regular monitoring of both salt iodization programs and of population iodine status. Excessive intake of iodine should be prevented, particularly in previously iodine-deficient areas, since a rapid increase in iodine intake in such populations may precipitate hyperthyroidism (5). However, the benefits of correcting iodine deficiency far outweigh the risks of salt iodization.

The importance of iodized salt use by the food industry. Because >80% of salt consumption in industrialized countries is from purchased processed foods, if only household salt is iodized, it will not supply adequate iodine intake. Thus, to control iodine deficiency successfully in industrialized countries, it is critical to convince the food industry to use iodized salt in their products. Switzerland's long-running iodized salt program has been successful because ~60% of salt used by the food industry is iodized on a voluntary basis (25). Iodine at ppm levels in foods does not cause any sensory changes, and the price difference between iodized and non-iodized salt is negligible. Thus, there are no major barriers to its use in processed foods in North America, and this practice should be encouraged.

Initiatives to lower sodium consumption. In order to decrease cardiovascular mortality worldwide, the WHO has recommended reducing salt intake to <5 g/day (<2000 mg sodium/day) in adult populations (51). Many countries are currently undertaking salt-reduction programs. If these initiatives are pursued without close coordination with salt iodization programs, there is the potential for a decrease in population iodine intakes as sodium intake decreases. This can be mitigated if salt iodization levels are adjusted upward as salt consumption decreases: iodine levels can be safely increased in salt to adjust for the recommended reduction in dietary salt (52). The Pan-American Health Organization and ICCIDD are currently studying the effects of sodium reduction initiatives on population iodine status and are working to develop model collaborative salt iodization–salt reduction programs (53).

Conclusions

Although substantial progress has been made over the last several decades, iodine deficiency remains a significant public health problem worldwide, including in developed nations. The ongoing monitoring of the population iodine status remains crucially important, and particular attention may need to be paid to monitoring the status of vulnerable populations. There is also a need for ongoing monitoring of iodized salt and other dietary iodine sources in order to prevent excess as well as insufficient iodine nutrition. Finally, it will be essential to coordinate interventions designed to reduce population sodium intake with salt iodization programs in order to maintain adequate levels of iodine nutrition as salt intake declines.

Author Disclosure Statement

The authors have no conflicts to disclose.

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