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"Gheorghe Asachi" Technical University of Iasi, Romania

HUMAN HEALTH RELATED TO IODINE ENVIRONMENTAL OCCURRENCE AND ITS DEFICIENCY IN WATER AND FOOD

Cristina Preda[1], Maria Christina Ungureanu[1*], Letitia Leustean[1], Cristina Cristea[1], Voichita Mogos[1], Carmen Vulpoi[1], Maria Gavrilescu[2,3]

[1] "Gr. T. Popa" University of Medicine and Pharmacy of Iasi, 1 Independence Blvd., 700111 Iasi, Romania
[2] "Gheorghe Asachi" Technical University, Faculty of Chemical Engineering and Environmental Protection, 73 Prof.Dr. D. Mangeron Street, 700050 Iasi, Romania
[3] Academy of Romanian Scientists, 54 Splaiul Independentei, RO-050094 Bucharest, Romania

Abstract

Iodine is essential for the synthesis of thyroid hormones which are extremely important in the process of growth and development of human body. The effects of iodine deficiency implies thyroid enlargement (goiter) and others disturbances so called iodine deficiency disorders (IDD). The iodine deficiency is an ancient but still existing problem with medical and environmental connotation. Soil and water from various regions worldwide are iodine deficient. This problem is aggravated by deforestation and soil erosion. The determination of iodine deficiency is mainly geological rather than social or economic.
Besides the fortification of different types of foods with iodine and iodization of salt, a multidisciplinary approach is necessary in order to provide the right amount of iodine to general population.

Key words: ecosystem, goiter, iodine, soil, thyroid hormones

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1. Introduction

There is an important relationship between: environment, health and diseases. Elements from: soil, water and air are major factors involves in important mechanisms vital for the proper functioning of the human body (Hlihor et al., 2009; Preda et al., 2012).

It is the case of iodine which is mandatory for the synthesis of thyroid hormones. As an important constitutive of thyroid hormones, iodine is involved in all their actions: growth, development and metabolisms. It is required throughout the life-cycle and is obtained through the diet (Brantsaeter et al., 2013). Deficient iodine intake is well known to be associated with reduced thyroid hormone production. The result of this deficit will be the goiter (thyroid enlargement) and a series of other disturbances, so called iodine deficiency disorders (IDD) (Zygmunt et al., 2012).

Iodine in excess can also have adverse effects depending on thyroid function, extent and duration of iodine excess (Brent, 2010). So, an optimal (regular and adequate) iodine amount reduces susceptibility to thyroid diseases which represents major public health problems.

The iodine deficiency is an old but still existing issue not only from the medical point of view but also from the environmental one. Soils from mountain regions (Himalayas, Alps) are iodine deficient. This problem is aggravated by deforestation and soil erosion. The food from iodine deficient regions will never provide the right amount of iodine to the population living there. Iodine deficiency results mainly from geological rather than social and economic conditions. Besides nutritional

[*] Author to whom all correspondence should be addressed: E-mail: mariachristina11@yahoo.com

iodine deficiency, a variety of other environmental, socio-economics and cultural factors are involved in aggravation of iodine deficiency (Kapil, 2007).

Iodine insufficiency is not only a problem in developing countries but also a major public health problem in many countries from Europe and Western world (Brantsaeter et al., 2013). In many parts of developed world the iodine deficiency has reemerged despite various programs to reduce its incidence (Blumenthal et al., 2012).

Therefore, in the last few decades, there has been remarkable progress in the global effort to eliminate iodine deficiency which is the world's greatest single cause of preventable brain damage (Brantsaeter et al., 2013).

2. Environmental occurrence of iodine

2.1. Iodine: general data

Iodine is a non-metallic microelement from the halogen family and exists in nature as a monovalent anion. The isotope I127 is the stable, naturally occurring iodine (Risher and Keith, 2009).

Like the other halogens, free iodine occurs mainly as a diatomic molecule I_2, which is toxic for eyes and lungs. Iodine in air can combine with water particles and precipitate into water or soils, where it combines with organic matter and remains in the same place for a long period of time. A number of analytical methods can be used to determine iodine level in air, water, soils and foods: ion chromatography, colorimetry, arsenic-cerium catalytic spectrometry (Risher and Keith, 2009).

2.2. Iodine cycle

Iodine is quite scarce in the environment, and even sea water contains a very low concentration of iodide well below that of fluoride, chloride and bromide (Rokita). The concentration in the earth's crust is 0,5 mg/kg and in the atmosphere the iodine concentration is 10-20 ng/m² (Risher and Keith, 2009). Iodine concentration in water and soil reflects the environmental iodine distribution and is an indirect index of environmental pollution and also is directly associated with the content of food iodine which affects living quality (Lu et al., 2005).

Environmental transport and distribution of iodine are performed by a complex of physical, chemical and biological mechanisms so called global iodine cycle (Fig. 1). During iodine global cycle, iodine is moved from soil and ocean sediment to water and the atmosphere (Risher and Keith, 2009).

The cycling of iodine through terrestrial ecosystem is poorly understood, due to its complex environmental chemistry and low natural abundance (Landis et al., 2012). The primary source of iodine on land is volatilization from the ocean surface (marine algae emit organic iodine vapour) (Risher and Keith, 2009). Brown algae of the Laminariales (kelps) remained a major source of iodine. They represent an important pump in the global biochemical cycle of iodine. In coastal regions Laminariales are a major contributor to the iodine flux from the ocean to the atmosphere through the production of volatile halocarbons (Kupper et al., 2008). Same orders of brown algae have developed a capability to accumulate and to use iodine in physiological adaptation to stress. Marine halogenated natural products have biological functions as defense compounds and signaling molecules for the producing organism (La Barre et al., 2010).

Combustions of fossil fuels also transfer the iodine to the atmosphere. Decay of the vegetation, volcanic activity, weathering of rock and human activities all contribute to the deposition of iodine in soil (Risher and Keith, 2009).

2.3. Iodine sources

The iodine **soil** status represents the relation between the supply of iodine and the soil's capacity to retain it. The coastal zones have the highest amount of iodine but the lowest capacity to retain it. There are many factors involved in the complex mechanism of iodine fixation in soil: acidity conditions, the chemical form of the iodine, the soil's organic content and texture (Johnson et al., 2003) (Table 1).

Organic-rich soils are not good providers of iodine in the food chain due to poor bioavailability (iodine is strongly fixed and not bioavailable). Iodide is the most mobile form in the soil comparing with iodate; acidic soil conditions are suited for iodide and alkaline oxidizing conditions are suited for iodate form (less soluble) (Johnson et al., 2003).

The iodine in surface **waters** is the best index of the environmental iodine status. The general level of iodine reported in rivers and lakes ranges from 1-10 μg/L (Johnson et al., 2003). The concentration of iodine differs depending on the water origin (Table 2). The **food** chain makes iodine available to humans. The sources of dietary iodine are: food and food additives (kelp, seaweed, iodinated salt, red coloring, iodine additives to bread/flour, therapeutics (Burek and Talor, 2009). Seafood is the most important source of iodine in the diet (the content of iodine in: marine seafood 160-3200 μg/kg, shellfish 0.798-1.6 mg/kg, kelp and seaweeds 1-2 mg/kg) (Risher and Keith, 2009).

The grazing animals and their products are also important suppliers of iodine, furthermore, during food production the level of iodine rise in milk, eggs and meat (use of fish flour as chicken food, iodates used as oxidants and a sanitizing agent in bread manufacturing, iodophors used as antiseptics in the dairy industry) (Johnson et al., 2003). In fact, the major source of iodine in highly developed countries are: dairy products (27-47 μg of iodine/kg), eggs (93 μg of iodine/kg), grain and cereal products (47 μg of iodine/kg) (Risher and Keith, 2009).

The iodine content in plants depends on the intake-retention ratio and a correct manipulation of this mechanism could improve iodine biofortification of crops leading to the prevention of iodine deficiency diseases (Landin et al., 2012).

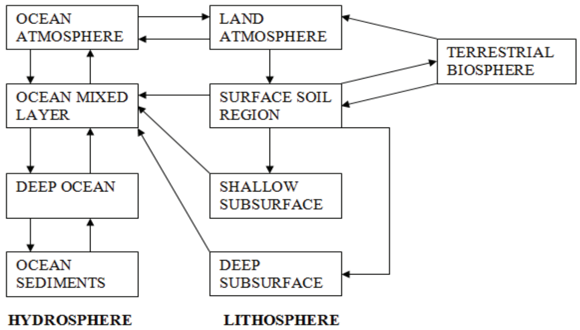

Fig. 1. Three groups of compartments with steady-state iodine content interconnected in order to show transfer rates among the ocean, land and terrestrial biosphere (Risher and Keith, 2009)

Table 1. Textural classification of soils according with iodine content (Johnson et al., 2003)

Soil	*Peat*	*Clay*	*Silt*	*Sand*
I (μg/g)	7	4.3	3	2.2

Table 2. Iodine content in sea, rain and river water (Risher and Keith, 2009)

	I concentration
SEAWATER	45-60 μg/L
RAINWATER OVER OCEANS	1-15 μg/L
RAINWATER OVER LAND	0,1-15 μg/L
RIVER WATER	0,1-18 μg/L

The iodine is not concentrated in the seeds but in leaves and so, the proportion of leaves make the difference regarding the iodine content (legumes > vegetables > fruits) (Johnson et al., 2003).

The absorption of dietary iodine is reduced by: nitrates, fluorides, calcium, magnesium, smoking, thiocyanates.

Iodine, in large quantities (from radiological contrast media, antiarrhythmic drug amiodarone, dental and skin disinfectants) may interfere with the normal distribution of iodine in human body.

3. Iodine and thyroid

3.1. General data

The healthy human body contains 15-20 mg of iodine, of which about 70-80% is present in the thyroid gland (Kapil, 2007).

Iodine is essential for the synthesis of thyroid hormones which are extremely important due to their action on virtually every cell in the body.

Growth and development are major process depending on thyroid hormones which implies a normal iodine intake.

Thyroid function and developmental abnormalities arise if the physiological requirements of iodine are not met. Public health consequences of severe iodine deficiency include: goiter, mental retardation, infant mortality and decreased fertility. Iodine deficiency is considered also as a variable involved in thyroid cancer etiology (Lukas et al., 2012).

About a third of the world's population live in iodine deficient areas. The iodine deficiency is exacerbated by the concomitant decrement in other nutrients such as: selenium, iron, zinc and vitamin A (Nyenwe and Dagogo-Jack, 2009).

3.2. Iodine and synthesis of thyroid hormones

Iodine from food, water or supplements is absorbed as molecular iodine by the stomach and duodenum; inorganic compounds of iodine are also rapidly absorbed when inhaled in vapour or aerosol form through the lungs. In the gastrointestinal tract, iodine, in form of water-soluble salts and food iodine are 100% absorbed compared to inorganig iodine and iodate which require reduction to iodide in the gut (Risher and Keith, 2009). The active transport of iodine from the blood into the thyroid is regulated by: Thyroid Stimulating Hormone (TSH) and by the concentration of iodine in the blood (Yarrington and Pearce, 2011). The thyroid gland has evolved not only to trap iodine avidly from dietary sources but also to store this element in organic form in order to maintain the secretion of thyroid hormones during periods of iodine deficiency.

In the thyroid gland iodine is oxidized to form "active" iodine which iodinate the tyrosine molecules and by coupling iodinated tyrosine residues form thyroid hormones: thyroxine (T4) and triiodothyronine (T3) (Yarrington and Pearce, 2011) (Fig. 2). The thyroid hormones acts through specific receptors in target organs leading to specific effects such as: increased basal metabolic rate, stimulation of normal growth and most of all normal levels of thyroid hormone are essential to the development of the fetal and neonatal brain.

3.3. Iodine deficiency disorders (IDD)

Iodine deficiency is defined by the WHO as a population median urinary iodine concentration (UIC) that falls below 100 μg/L: 50-99 μg/L is mild, 20-49 μg/L is moderate and < 20 μg/L is severe (Skeaff et al., 2012).

The most severe IDD are encountered when iodine deficiency affects embryonic and fetal development. Many of the underlying anatomical lesions occur during the early stages of intra-uterine development and the damage is irreversible by birth. So, the effects of severe iodine deficiency depend upon the period of life exposed to this deficit (Table 3). Mild iodine deficiency may influence developmental impairment in children. There are limited studies reporting association between prenatal iodine status or suboptimal maternal iodine intake and cognitive function of infants and children up to 18 months (Brantsaeter et al., 2013, Gunnarsdottir and Dhal, 2012).

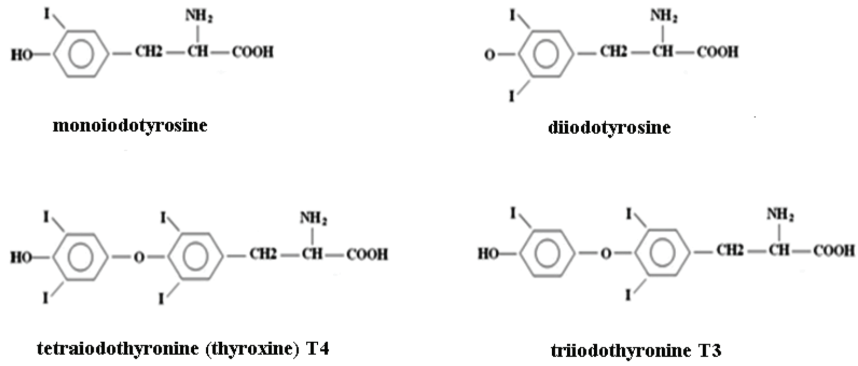

Fig. 2. Structure of thyroid hormones and precursors

Table 3. Functional and developmental disorders associated with severe iodine deficiency

Period	*Disorders*
Fetal	Abortions Stillbirths Congenital anomalies Endemic cretinism
Child	Goiter Impaired mental function Retarded physical development Increased susceptibility to nuclear radiation
Adult	Goiter Impaired mental function Hypothyroidism Increased susceptibility to nuclear radiation

The psychomotor and mental performances of a population are adversely affected when fetuses and neonates are exposed to moderate or mild levels of iodine deficiency. In pregnant women with normal thyroid function, mild iodine deficiency is present in 66% during the first trimester. In the third trimester the prevalence of iodine deficiency is present in ¾ of cases (Bruker-Davis et al., 2012). While the neuro-cognitive development is dramaticaly damaged in severe form of iodine deficiency the consequences of mild forms of iodine deficiency is still less documented.

The population most assessed to reveal iodine deficiency is school-age children because it is very efficient and practical to survey such group (Zygmunt et al., 2012). In order to evaluate the iodine status several criteria are used: assessment of thyroid volume by ultrasound (when more than 5% of school children population present enlargement of the thyroid it is called endemic goiter), measurement of urinary iodine concentration (UIC), measurement of neonatal TSH (recommended only to detect severe iodine deficiency), measurement of plasma tyroglobulin (Vandevijvere et al., 2012; Zbranca et al., 2008).

The best parameters to evaluate the iodine deficiency are: goiter incidence and iodine urinary concentration (Vulpoi et al., 2002). Urinary iodine concentration (UIC) is a good marker for recent dietary intake of iodine. It is now the index of choice for evaluating the degree of iodine deficiency and for monitoring its correction (Zygmunt et al., 2012). Using all this parameters is possible to classify the degree of iodine deficit (Table 4).

3.4. Prevention of IDD

More than 2 billion people are at risk to develop iodine deficiency (Campbell et al., 2012). According to World Health Organisation (WHO), during 1993-2003, a number of 54 countries suffered from iodine deficiency and 3 billion peoples had insufficient iodine intakes, infants, pregnant and lactating women being among those most affected (Mirmiran et al., 2012).

The recommendations of WHO-United Nation Children’s Found (UNICEF)-International Council for the Control of Iodine Deficiency Disorders (ICCIDD) for adequate iodine intake are: 150 μg/ day for adults, 220-290 μg/ day for pregnant and lactating women (Campbell et al., 2012). The globally strategy to prevent IDD is universal salt iodization, which is safe, cost-effective and sustainable.

Even the risk of iodine excess is low, regular monitoring of urinary iodine is recommended also, more research on the impact of the excess iodine intake is necessary (Wu et al., 2012). WHO and UNICEF recommendation for controlling iodine deficiency disorders is universal salt iodization (USI), which consist of adding iodine (as iodate or as iodide) to all salt for human consumption.

Table 4. Classification of the iodine deficiency according to: goiter, TSH and IUC (Zbranca et al., 2008)

Parameter	***Normal***	***Mild***	***Moderate***	***Severe***
Schoolchildren and adults				
goiter incidence	< 5	5- 19.9	20- 29.9	≥ 30
UIC (μg/dl)	> 10	5- 9.9	2- 4.9	< 2
Newborns				
incidence of TSH > 5mUI/l (%)	< 3	3- 19.9	20-39.9	≥ 40
UIC (μg/dl)	> 10	3.5-9.9	1.5-3.4	< 1.5

This procedure is highly effective and low-cost. The current WHO-UNICEF-ICCIDD guideline recommends salt iodization in the range of 20-40 mg of iodine per kg of salt (Campbell et al., 2012).

The two most commonly used vehicles for iodine supplementation are: salt iodization and iodized oil injections. There are operational difficulties in the implementation of iodized oil injection program (availability of trained staff to administer injections and population approach to this procedure) and also for the iodized salt program (lack of infrastructure, resistance of the population to change the type of salt they are consuming) (Pandav, 2012).

Since 1999 the number of products to which iodised salt could be added was increased due to the change of dietary habits to include: breakfast cereals, breakfast biscuits, crisp bread and pickling brine in the production of meat products (Vandevijvere, 2012).

Biofortification of vegetables with iodine provides a mild but significative increase in urinary iodine concentration and together with the habitual use of iodized salt may contribute to the improvement of iodine nutritional status of populations (Tonacchera et al., 2013).

The fortification of bread significantly increased urinary iodine concentration but not to a level compatible with iodine sufficiency, suggesting that supplements are still required despite the iodized salt initiative in bread and cereal production (Clifton et al., 2013).

Iodine enrichment in yest- creating a technology of iodine-enriched yeast production is of strong necessity and could be applied in both human and animal nutrition (Dolinska et al., 2012).

To prevent the iodine deficiency in pregnant women was necessary in some countries to offer iodine, iron and folic acid tablets and for neonates and children under 5 years iodine and iron supplements (Tonmukayakul et al., 2012).

For the developing countries the main methods used to combat iodine deficiency are: iodization of salt (requires special packaging and national commercial networks), intramuscular injection of iodinated oil (costly and requires medical intervention), oral intake of iodinated oil (costly, requires distribution infrastructure and long-term compliance) (Fish et al., 1993).

The benefits of correcting iodine deficiency (decreased prevalence of goiter and other thyroid disturbances) are far more important than the possible thyroid disorders induced by the iodine supplementations (hyperthyroidism or hypothyroidism in elderly) (Lombardi et al., 2013).

Unfortunately not all countries have legislation for mandatory salt iodization and iodized salt quality and thereby population iodine status is not controlled appropriately in many countries (Mirmiran et al., 2012).

Despite the universal salt iodization, mild iodine deficiency has re-emerged in some country from Europe, Australia due to changes in food pattern (Skeaff et al., 2012).

Besides medical intervention (enhancement of iodine in food and drink or by oral or parenteral iodine administration) the environmental measures are necessary: preventing the removal of iodine by flooding, improving the ability of the soil to fix iodine, changing crops development, reducing iodine volatilization from the soil-plant system (Johnson et al., 2013). Also there are several environmental contaminants (perchlorate, thyocianate and nitrate) which in pharmacological doses can affect iodine uptake and so the thyroid function (Pistea et al., 2013, Yarrington and Pearce, 2011, Zewdie et al., 2010). The consumers, food producers, media representatives, public health professionals and healthcare workers must be educated by all interventions and measures possible in order to better understand the necessity of a healthy diet (Vandevijvere, 2012).

4. Conclusions

The iodine deficiency is one of the must important public health problems not only in developing countries but also for the Western Europe and Australia. In spite of many efforts that began more than 30 years ago, the issue of iodine deficiency reemerges.

The medical measures will not solve the entire problem, a multidisciplinary approach is necessary: educational programs for healthcare providers and population, social and economical measures and environmental strategies in order to prevent the removal of iodine from the soil and the volatilization of iodine from the soil-plant systems.

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