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THE INFLUENCE OF ADVERSE ENVIRONMENTAL FACTORS ON THE FREQUENCY OF THYROID PATHOLOGY AMONG THE POPULATION

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Abstract

Thyroid diseases arise from both internal and external factors. Changing environmental and radiation conditions are increasing their prevalence and altering thyroid disease patterns. This review highlights current insights into how environmental influences affect thyroid structure and function, outlining recent discoveries, mechanisms, and areas needing further research.

The purpose of the study. To review scientific literature that investigates the effects of adverse industrial environmental factors on thyroid gland function.

Materials and Methods. A search for relevant studies was conducted in electronic databases, including PubMed, Web of Science, and Scopus, using specific terms and keywords. Only original observational studies examining the impact of harmful environmental factors on the development of thyroid pathology were included.

Results. High levels of heavy metals (Pb, Hg, Cd, As) are linked to increased thyroid cancer risk. In oil and gas regions, children exhibit elevated levels of manganese, boron, vanadium, and silicon in their hair, which can interfere with iodine uptake and lead to iodine deficiency. Cadmium lowers thyroid-stimulating hormone, contributing to hyperthyroidism. Radiation-exposed areas (e.g., Chernobyl, Semipalatinsk) show more nodules and autoimmune thyroiditis. Fine particles (PM2.5, PM10) increase the risk of thyroid cancer, and prenatal air pollution affects newborn T4 levels. Organic and inorganic pollutants disrupt thyroid hormone production and promote cancer.

Conclusion. Environmental contaminants, including heavy metals, radiation exposure, industrial residues and pollutants, and endocrine-disrupting chemicals, play a significant role in the occurrence and progression of thyroid disorders. The rise in chronic diseases, including thyroid pathologies, serves as a marker of environmental pollution. Further research is needed to explore the mechanisms by which environmental factors affect thyroid function. It is essential to develop prevention and monitoring strategies, particularly in environmentally unfavorable regions.

Keywords: *thyroid dysfunction, endocrine disruptors, environmental exposure.*

Introduction

In recent decades, developed countries have increasingly raised concerns about the negative impact of environmental contamination by metals, as well as deficiencies in essential chemical elements. These issues are associated with changes in population dietary patterns, environmental and industrial factors, changes in life expectancy and morbidity patterns, and high levels of pharmaceutical burden. Understanding the impact of environmental factors and contaminants on thyroid function is crucial for developing effective preventive measures and policies that ensure proper development and maintain healthy metabolism in future generations, as well as for preventing thyroid diseases and cancer in adults and elderly populations. Despite the diminutive size of the thyroid gland, its malfunction can disrupt a multitude of metabolic processes and exert a profound impact on the well-being of nearly all bodily organ systems. The range of thyroid ailments spans from subtle structural alterations to severe functional and morphological irregularities, the latter frequently compromising patients' quality of life and, in certain instances, their life expectancy [1-3]. Thyroid disease is a very common condition that influences the entire human body, including cognitive function and mental health. As a result, thyroid disease has been associated with multiple neuropsychiatric conditions. Thyroid hormones lay a crucial role in the functioning of the nervous, reproductive, and cardiovascular systems in both children and adults [4-6].

Environmental factors, including climate change, pollution, dietary changes, and exposure to chemicals, have been recognized as impacting thyroid function and health. Thyroid disorders and cancer have increased in the last decade, the latter increasing by 1.1 % annually, suggesting that environmental contaminants must play a role [7]. Global warming changes thyroid function, and living in both iodine-poor areas and volcanic regions can represent a threat to thyroid function and can favor cancers because of low iodine intake and exposure to heavy metals and radon [7-9]. High concentrations of nitrate and nitrite in water and soil also negatively impact thyroid function [10]. Air pollution, particularly particulate matter in outdoor air, can worsen thyroid function and can be carcinogenic [11]. Environmental exposure to endocrine-disrupting chemicals can alter thyroid function in various ways, as some chemicals can mimic and/or disrupt thyroid hormone synthesis, release, and action on target tissues, including bisphenols, phthalates, perchlorate, and per- and polyfluoroalkyl substances [12].

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Results

Many factors, endogenous and exogenous, influence the development of thyroid diseases. The constantly changing ecological and radiological situation contributes to the increasing incidence of thyroid diseases and alters the structure of thyroid pathology [13]. The combined impact of anthropogenic and geochemical factors continuously deteriorates medical and demographic indicators, increasing chronic diseases and thyroid gland pathology [14]. Environmental factors are determinants for the appearance of autoimmune thyroid diseases in susceptible subjects. Increased iodine intake, selenium, and vitamin D deficiency, exposure to radiation from nuclear fallout or due to medical radiation, are environmental factors increasing autoimmune thyroid diseases [15;16].

Iodine deficiency remains a major public health problem in many parts of the world, especially in areas where naturally low iodine levels in the environment, including soil and water, result in reduced iodine intake from daily food products. Long-term iodine deficiency leads to the formation of iodine deficiency disorders such as diffuse and nodular/multinodular goiter, thyrotoxicosis on the background of nodular thyroid pathology, congenital hypothyroidism, mental and physical retardation of children, and miscarriage [17-19]. The description of cretinism in areas with severe iodine deficiency provided the first historical evidence of the consequences of abnormalities in maternal thyroid function in pregnancy. The important role of maternal thyroid hormones in fetal brain development was further substantiated by the paucity of neurological symptoms in children with congenital hypothyroidism who received prompt treatment immediately after birth and by the measurement of thyroxine (T4) in cord blood from newborns who were unable to synthesize thyroid hormones due to a defect in organification [20]. The presence of endemic goiter in pregnant women has a pronounced negative impact on the thyroid function of newborns [21; 22]. Conversely, areas with sufficient or excessive iodine intake are particularly associated with autoimmune thyroid pathologies (such as Hashimoto's thyroiditis and Graves' disease), as well as the development of diffuse goiter [17].

Iodine deficiency occurs when there is an insufficient intake of iodine-containing foods, the presence of substances in food that inhibit iodine absorption (such as bromine, fluorine, and chlorine), the use of certain medications (including lithium salts, sulfonamides, and excessive calcium supplements), increased radiation levels, and environmental pollution. An imbalance of several trace elements, such as zinc, selenium, cobalt, manganese, and copper, can exacerbate iodine deficiency even under normal iodine intake. Antithyroid (goitrogenic) effects are caused by iodine antagonists – fluorine, lithium, arsenic, mercury, antimony, and sulfur-containing organic compounds of humic acid [23].

In a cross-sectional observational study in Shaanxi Province (China), the relationship between selenium status, dietary factors, and pathological thyroid conditions was investigated. In the adequate-selenium county, the prevalence of pathological thyroid disorders (subclinical hypothyroidism, hypothyroidism, AT, and enlarged thyroid) was significantly lower than in the low-selenium county [15]. A paper by Esposito D, et al. evaluated the real efficacy of selenium supplementation in Hashimoto's thyroiditis by measuring thyroid-stimulating hormone, thyroid hormones, thyroid peroxidase antibodies, and thyroglobulin antibodies levels, as well as thyroid echogenicity after 6 months of L-selenomethionine treatment [24].

Adverse technogenic factors have a predominant influence on the elemental status of populations working in hazardous industries or living near industrial enterprises, leading to maladaptation and a reduction in the functional reserves of the population, including due to trace element imbalances [25]. Results have also been obtained proving the impact of oil and gas extraction on the severity of iodine deficiency conditions in children. It has been noted that in regions with oil and gas industries, the content of manganese, boron, vanadium, and silicon in children's hair is much higher than in areas with favorable conditions. These elements can act as competitors to iodine in forming vital chemical bonds in the child's body [26].

Heavy metals and thyroid dysfunction. Humans are exposed to a significant number of chemicals that are suspected of disrupting hormone homeostasis. Hence, in recent decades, there has been a growing interest in endocrine-disrupting chemicals. Recent studies have pointed to the important role of environmental factors, especially heavy metals, in promoting thyroid cancer incidence. Water, soil, and atmosphere are vehicles that may be enriched with heavy metals due to their proximity to sources, including natural emissions (non-anthropogenic) and pollution secondary to human activities (anthropogenic). Industry, agriculture, and technology are activities associated with higher exposure to heavy metals [27].

Many potentially hazardous chemical elements for human health (As, Cd, Hg, Pb, Ni, V) enter the human environment in large quantities from industrial sources and vehicle emissions (Pb, Pt, Sn, etc.). Additionally, toxic metals such as arsenic, mercury, and cadmium are components of herbicides, pesticides, and chemical fertilizers. In this regard, an important aspect of the endemic problem is its combined variant (iodine deficiency in the body and the influence of xenobiotics – environmental stressors), which manifests as a mutual exacerbation effect. This does not exclude the possibility of the formation of an endemic solely due to the increased presence of xenobiotics in the environment. As, Br, Cd, Hg, Mn, Se, and Sn showed significantly higher concentrations in the thyroid than in the other tissues. In particular, cadmium, mercury, arsenic, lead, manganese, and zinc exhibit the capacity of EDCs to disrupt the hormonal system, as well as act as carcinogens, promoting malignant transformation. In this context, arsenic, beryllium, cadmium, chromium, hydrargyrum, and nickel are identified as either definite or probable carcinogens (class 1) according to the International Agency for Research on Cancer (IARC, December 2022). In the volcanic area, where the thyroid cancer incidence is doubled, many metals such as As, B, Cd, Hg, Mn, Mo, Pd, Se, U, V, and W (Tungsten) were significantly increased by three- to 50-fold in both water and lichens, documenting metal pollution in the environment. A higher risk of thyroid carcinomas was particularly observed in various volcanic areas around the world, including Hawaii, Iceland, French Polynesia, and Sicily in Italy. The increased content of heavy metals in soil and, consequently, in plants grown in these areas, as well as atmospheric pollutants (CO_2, sulfur, and chlorine compounds) or other potential thyroid disruptors contained in waters such as fluorine, sulfur, and selenium, could be responsible for the higher incidence of thyroid tumors [28-32].

Cd is known to act as a thyroid disruptor and carcinogen in humans. This widespread toxic metal has been shown to disrupt thyroid function and act as a carcinogen in both animals and humans [33]. The primary accumulation sites for Cd are the liver, kidneys, and muscles. Additionally, the thyroid gland may also serve as a site for Cd deposition, owing to the presence of cysteine-rich proteins called metallothioneins, which bind to Cd and act as a powerful intracellular detoxifier of the metal [34].

The study found that elevated blood Cd levels were linked to lower TSH levels, indicating that this inverse relationship may point to thyroid dysfunction caused by Cd exposure. Higher Cd levels were observed to be associated with lower TSH levels and higher risk of thyroid dysfunction. In contrast, urinary Cd levels correlated with higher T3 and T4 levels but did not affect thyroid-stimulating hormon levels, which may indicate secondary hyperthyroidism. When comparing blood and urine Cd levels, urine Cd reflects the total body burden, whereas blood Cd levels indicate more recent exposures [35; 36]. Based on these findings, we can hypothesize that thyroid hormone levels are closely related to total Cd body burden, while changes in TSH levels are more indicative of recent Cd exposure.

In a study analyzing NHANES data from 2007 to 2010 [37], Luo and Hendryx found that the effect of Cd exposure on the thyroid axis may differ between sexes. They observed a positive correlation between Cd exposure and log-Tg in both genders, while the correlation between Cd exposure and total T3 levels was only significant in males. These gender differences are not easily explained and may be due to variations in toxicokinetics and hormonal differences between males and females, which likely influence the observed outcomes. Studies by Rosati et al. [38] and Jurdziak et al. [39] have highlighted the impact of occupational Cd exposure. An outdoor study involving 277 individuals of both genders exposed to urban pollutants found a negative correlation between urinary Cd levels and free T3 and T4 levels, and a positive correlation between urinary Cd levels and TSH levels, suggesting that occupational exposure to the low Cd concentrations found in urban air can affect thyroid function [38]. In another study, workers occupationally exposed to Pb, Cd, and arsenic also confirmed that higher blood Cd concentrations amplify the risk of abnormal thyroid hormonal function, as evaluated by elevated TSH levels [39].

Recent human studies have investigated the potential role of Cd in autoimmune thyroid diseases. A study based on the 2014 SPECT-China survey, which involved 5,628 Chinese adults, revealed a link between blood Cd levels and antibodies to thyroid proteins, as well as thyroid dysfunction, as indicated by total T3, total T4, and TSH levels [40]. Moreover, a cross-sectional case-control study examining the levels of certain essential elements, toxic metals, and metalloids (including Cd) in the blood of 22 women found that patients with Hashimoto's thyroiditis and overt hypothyroidism had higher Cd levels compared to 55 healthy women [41]. A study conducted on three-year-old children living near an informal e-waste recycling area in China assessed the impact of thyroid disruption on their mental development, focusing on the role of Cd and Pb blood levels in these processes [42]. Significantly higher blood levels of Cd and Pb, as well as higher FT4 and TSH concentrations, and reduced cognitive and language scores were observed in children residing near an e-waste area compared to the reference group.

Thyroid cancer has become the 9th most common cancer (5th in women, 16th in men) [43; 44], and if current trends continue, it could become the 4th most common cancer by 2030 [45]. Recent evidence suggests that Cd may contribute to thyroid cancer development due to its endocrine-disrupting properties [46]. As highlighted in a recent review by Vigneri et al. [27], epidemiological studies have shown a higher incidence of thyroid cancer in volcanic regions affected by non-anthropogenic heavy metal pollution, with Cd being one of the key contributors. Furthermore, analysis of Cd concentrations in autopsy samples from retired Idrija residents and mercury mine workers revealed unusually high levels of Cd in the kidney cortex and thyroid glands, suggesting potential bioaccumulation in the thyroid. The study found that higher Cd levels in tissues were linked to more advanced stages of thyroid cancer. Chronic accumulation of Cd in thyroid tissue was identified as one of the contributing factors to the progression of thyroid cancer [47,48].

Studies have shown that mercury (hereinafter – Hg) can accumulate in the thyroid gland among occupational workers and surrounding residents, particularly in those population groups that consume large amounts of fish from polluted reservoirs, leading to altered levels of T3 and T4 and disrupting the body's metabolic balance. In addition, mercury exposure has been associated with an increased incidence of thyroid autoimmunity, particularly Hashimoto's thyroiditis [47]. Chung et al. [48] examined 92 Korean women undergoing thyroidectomy to evaluate the association between blood and tissue levels of heavy metals and different stages of thyroid cancer. The available evidence demonstrated that Hg vapor exposure may affect thyroid function in chlor-alkali workers [49].

Exposure to high levels of manganese (hereinafter – Mn), either from environmental or occupational sources, causes a neurodegenerative condition like idiopathic Parkinson's disease, known as manganism. Both manganism and Parkinson's disease are characterized by alterations in dopamine and its metabolites, which are capable of inhibiting TSH secretion. Dopamine and dopaminergic receptors are crucial for neurodevelopment and TSH modulation. This suggests that excessive Mn exposure during pregnancy may lead to altered neurodevelopmental outcomes due to the dysregulation of dopaminergic control over TSH and thyroid hormone levels [50]. Research has shown that abnormal thyroid hormone levels resulting from high Mn exposure during pregnancy are linked to adverse neurodevelopmental consequences [51].

Of the inorganic forms of arsenic (hereinafter – As), arsenate is the most toxic to endocrine glands. Moreover, a methylated arsenic compound (dimethyl arsenic acid) has been shown to promote carcinogenesis in various organs of rats, including the thyroid [52]. In a volcanic area of French Polynesia, where thyroid cancer rates are high, the risk of developing papillary thyroid cancer rises by 30 % for every 1 µg/d/kg increase in As intake, even though the intake remains within the levels recommended by the WHO. However, this increase in thyroid cancer risk was especially pronounced in individuals with first-degree relatives who had a history of cancer [53], suggesting that As may act as a cocarcinogen, amplifying the effect in those with genetic susceptibility.

High blood lead levels are associated with elevated TSH levels in individuals with occupational lead exposure [54]. Li and his colleagues investigated 96 cases of papillary thyroid carcinoma, 10 cases of nodular goiter, and seven cases of thyroid adenomas in Chinese patients with various thyroid disorders to assess the relationship between lead (hereinafter – Pb) and thyroid function. The study measured T3, FT3, FT4, TSH, and serum lead levels, finding that lead concentrations were significantly higher in thyroid adenomas and lower in nodular goiters compared to PTCs. Even after sex stratification, the disparity increases among women. According to the study, lead could have various etiological effects on thyroid conditions, including thyroid cancer [55].

Shen et al. observed elevated copper (Cu) levels and reduced selenium (hereinafter – Se) and magnesium (hereinafter – Mg) levels in patients with thyroid cancer compared to healthy controls [56]. Similarly, Gumulec et al. reported significantly decreased zinc (hereinafter – Zn) levels in the thyroid tissue of thyroid cancer patients compared to controls [57]. The potential causal link between metals and thyroid cancer is further supported by the impact of the heavy metal copper on $BRAF^{V600E}$ mutation-driven carcinogenesis [58; 59].

All vanadium compounds are toxic [60]. Some researchers have associated vanadium with thyroid cancer. In their study, Fallahi et al. examined the effects of V_2O_5 on the proliferation and chemokine release of healthy thyrocytes. They discovered that V_2O_5 can stimulate the secretion of T-helper 1 chemokines, such as interferon and tumor necrosis factor, and enhance the impact of these chemokines in the thyroid [61].

Effects of Particulate Matter Exposure on Thyroid Function. Giannoula et al. demonstrated in an ecological study that specific components of air pollution could contribute to an increased incidence of thyroid cancer [62]. It has also been reported that elevated levels of $PM_{2.5}$ and PM_{10} (which serve as indicators of air pollution) are carcinogenic to humans and harmful to the endocrine system [63]. Cong reported a positive correlation between exposure to ambient air pollution from waste gas emissions and an increased incidence of thyroid cancer [64]. Research has shown that prenatal exposure to $PM_{2.5}$ and PM_{10} air pollution was associated with higher newborn total T4 concentrations [65,66]. Howe et al. identified pregnancy months 3 to 7 as critical windows for PM2.5 exposure and months 1 to 8 for PM10 exposure, both of which were associated with higher levels of thyroxine [65]. Irizar et al. also proposed that exposure to $PM_{2.5}$ during pregnancy was positively associated with TT4 levels in newborns. Specifically, TT4 levels measured three days after birth increased by 0.206 μg/dl for every 1 μg/m^3 increase in $PM_{2.5}$ exposure during pregnancy [66].

Research conducted in the US [67] and Brazil [68] has highlighted an association between particulate matter and the onset of thyroid cancer. Specifically, a 10 μg/m^3 increase in PM2.5 concentrations over periods of 12, 24, and 36 months was associated with a higher likelihood of developing Papillary Thyroid Carcinoma (hereinafter – PTC), with the risk increasing as the duration of exposure increased. Additionally, a study involving 550,000 patients in China found that emissions from industrial waste gases, mainly consisting of particulate matter, sulfur dioxide, and nitrogen dioxide, were correlated with a higher incidence of thyroid cancer [69].

Exposure to pesticides and the risk of thyroid disease. Studies have indicated that early pesticide exposure may impact thyroid hormone levels in newborns, increasing the risk of developing thyroid tumors in adulthood [70]. Studies have investigated the link between pesticides and thyroid cancer. Furthermore, pesticides disrupt thyroid function through several mechanisms, including inhibiting iodine uptake, enhancing the clearance of thyroid hormones, interfering with the activities of iodothyronine deiodinase and thyroid peroxidase, hindering cellular uptake of thyroid hormones, and modifying thyroid gene expression. Consequently, alterations in thyroid hormone function can result in abnormal proliferation of thyroid tissue, leading to oncogenesis [71].

Dichlorodiphenyltrichloroethane (hereinafter – DDT) and its primary metabolite dichlorodiphenyldichloroethylene (hereinafter – p-DDE) are among the most extensively studied organochlorine pesticides (hereinafter – OCPs) known for their endocrine-disrupting properties. Research has shown that thyroid hormone synthesis can be disrupted by DDT and hexachlorobenzene (hereinafter – HCB) [72]. A recent study found a positive association between lindane, an OCP classified as carcinogenic by the IARC, and thyroid carcinogenesis [73].

Atrazine (a triazine herbicide) and Malathion (an organophosphate insecticide) have been associated with an increased risk of thyroid cancer in individuals exposed to pesticides on farms [74]. In a study by Zeng et al., a significant relationship was observed between thyroid cancer risk and occupational exposure to biocides and pesticides among workers, compared to exposure to other harmful substances [75]. A prospective cohort study conducted in Iowa and North Carolina (1993-1997 for enrollment and 1999-2005 for follow-up) found that pesticide use, including fungicide (metalaxyl) and the OCP lindane, was associated with increased hazard ratios (HR) for thyroid cancer, respectively exposure to Malathion, an organophosphate pesticide, in the environment has been linked to an increased risk of thyroid cancer in females who work and live in agricultural areas [76]. Research conducted in Norway also found a positive link between chlordane and HCB serum OCP metabolites and the rising incidence of thyroid cancer [77].

Nitrate is a prevalent contaminant in drinking water, especially in agricultural regions, where the use of nitrogen-based fertilizers is common. High amounts of nitrate might also be present in some fruits and vegetables [78]. Nitrogen dioxide (NO_2), a reactive gas found in polluted air, has been linked to carcinogenesis. It can trigger free radical reactions by interacting with unsaturated fatty acids and promoting the autooxidation of organic compounds. Chronic exposure to NO_2 has been associated with an increased risk of lung cancer, with potential mechanisms including genomic instability and thyroid hypertrophy caused by the overproduction of cellular reactive oxygen species. In addition, NO_2 is identified as a potential endocrine disruptor. Previous research has shown a significant correlation between higher NO_2 concentrations in air pollutants and an increased likelihood of developing primary hypothyroidism [79]. A study conducted in China found that increased maternal exposure to NO_2 was associated with a higher risk of congenital hypothyroidism in newborns [80]. Research from Bulgaria, Slovakia, Germany, and the USA has shown links between nitrate exposure and thyroid function across various age groups. Some studies indicated that schoolchildren and pregnant women exposed to elevated nitrate levels (75 mg/L) in drinking water faced an elevated risk of developing goiter and thyroid disorders [81; 82].

Radiation and thyroid function. Ionizing radiation is another important environmental pollutant that affects thyroid health. Exposure to ionizing radiation occurs through medical treatments, nuclear accidents, or environmental sources. The association between radiation exposure and the occurrence of TC has been well documented. The thyroid tissue is sensitive to radiation. Ionizing radiation proved to be carcinogenic (group 1) by IARC [83].

Moreover, the thyroid gland is susceptible to radioiodine exposure. The main fission product of uranium and plutonium is iodine-131 (^{131}I), which accounts for 3 % of all fission products. It is connected to nuclear energy and diagnostic and therapeutic processes in medicine [84].

Ionizing radiation, particularly from nuclear accidents, has been linked to a dramatic increase in thyroid cancer, particularly papillary thyroid carcinoma, the most common type of thyroid cancer. The Chernobyl disaster is a striking example: the release of radioactive iodine led to a dramatic increase in the number of thyroid cancers, especially among children and adolescents. The prevalence of thyroid autoantibodies increased in children and adolescents exposed to radiation about 6-8 years after the Chernobyl accident. Thyroid peroxidase antibodies prevalence was higher in radiation-exposed Belarusian children (6.4 % versus 2.4 % in unexposed children) and in adolescents exposed to radioactive fallout 13-15 years after the Chernobyl accident [85]. More than 11,000 thyroid cancer cases were exposed during childhood in Ukraine, Belarus, and Russia [86]. Importantly, PTC was the most common thyroid cancer type among these children [87].

Children in Japan were exposed to radiation from US atomic bombings in 1945, and teenagers exhibited an elevated risk of acquiring thyroid cancer five decades later [88; 89]. It has been established that the rise in TC is caused by increasing radiation dose and exposure time [90].

The rapid development of the nuclear and uranium mining industries, along with the prolonged testing of nuclear weapons at the Semipalatinsk nuclear test site, introduced a vast number of radioactive substances into the living environment of Kazakhstan's population. This resulted in radiation contamination of large areas and exposure of the population. The residents of East Kazakhstan, Pavlodar, and Karaganda regions, adjacent to the former Semipalatinsk nuclear test site, were particularly affected by radiation exposure. The population of the Aktobe region continues to be exposed to ionizing radiation due to living in areas near oil and gas production facilities [91; 92].

The tragic feature of the Semipalatinsk region lies in the repeated acute and chronic radiation exposure of the population in both high and low doses, the virtually complete absence of decontamination of the area, and the lack of replacement of food products. Zh. Espenbetova et al. examined 4,083 people living in the Semipalatinsk region, aged 16 to 84 years (mean age 49±2.8 years), comprising 1,836 men and 2,247 women. Ultrasound scanning of the thyroid gland parenchyma revealed that diffuse goiter was predominant in all age groups (39.1 %), mostly observed in individuals under 40 years old. In individuals aged 40 years and above, nodular thyroid formations and autoimmune thyroiditis were significantly more common (28.4 % and 24.1 %, respectively; $p < 0.05$). The linear parameters and volume of the thyroid gland in the population turned out to be significantly lower compared to the normative indicators. The decrease in the volume of the gland in this case can be explained by the long-term effects of exposure to low doses of ionizing radiation, which contribute to the development of progressive atrophy of the thyroid parenchyma. Two forms of thyroid cancer have been identified: follicular and papillary. At the same time, papillary carcinoma was diagnosed in most cancer cases (81.5 %), which corresponds to the literature data. A study of hormonal status among the population of the region revealed a significant predominance of thyroid hypofunction, detected in 42.42 % of cases. A thyroid gland functional state analysis revealed a statistical predominance of euthyroidism in the surveyed areas [93].

In addition, chronic exposure to low levels of radiation from environmental sources has been associated with an increased risk of hypothyroidism, thyroid nodules, and thyroid cancer. In regions polluted by radionuclides and heavy metals, individuals have shown higher rates of hypothyroidism and other thyroid pathologies.

Uranium and thorium are the primary sources of alpha radiation, which can irradiate neighboring, closely located non-irradiated cells. This contributes to an increase in intracellular energy, leading to an acceleration of metabolic processes, primarily in thyroid cells, also known as thyrocytes. It is known that in iodine-deficient, goiter-endemic regions, uranium accumulates in the thyroid gland in elevated amounts. According to data, the thyroid glands of animals from goiter-endemic areas contain the highest levels of alpha-emitting nuclides (uranium, thorium, and their decay products) – up to 3.0 pCi/g (compared to 0.09–0.17 pCi/g in bones). This increase in thyrocyte volume leads to an enlargement of the thyroid gland, contributing to the development of goiter associated with autoimmune thyroiditis [94].

Studies have shown that children who consumed water contaminated with radionuclides, such as uranium, thorium, and strontium, had a significantly higher incidence of autoimmune thyroiditis. Among children aged 12 to 16 with goiter, who consumed water contaminated with highly toxic radionuclides, autoimmune thyroiditis was found in 43.5 % of cases, which is 30 times more frequent than in children who consumed water without radionuclides (1.47 %). It was shown that autoimmune thyroiditis was detected in all children with thorium levels in hair above the norm. Uranium levels above the established norm were found in 97.1 % of the children, and thorium levels above the norm in 26.08 % of the schoolchildren. Among schoolchildren with uranium levels above 0.06 µg/g and thorium levels above the norm (i.e., 0.01 µg/g), an enlargement of the thyroid gland was found in all children, with autoimmune thyroiditis developing in 90.9 % and 100 % of the children, respectively, with uranium and thorium levels above the norm [95].

Discussion

Thyroid disorders arise from a complex interplay of endogenous and exogenous factors, with environmental exposures being particularly influential [13]. The results of our study are consistent with existing evidence indicating a multifactorial influence of environmental and geochemical factors on the development and progression of thyroid diseases [14-16; 23].The findings support the hypothesis that both iodine deficiency and exposure to environmental pollutants – such as radiation, heavy metals (e.g., mercury, arsenic), and trace element imbalances – play a significant role in altering thyroid function [17-19]. Heavy metals such as lead, mercury, cadmium, and arsenic can accumulate in thyroid tissue, disrupt hormone regulation, and act as carcinogens [7-10]. In particular, cadmium demonstrates a strong disruptive potential, with several studies reporting its association with altered levels of TSH, T3, and T4, as well as its accumulation in the thyroid gland and its carcinogenic effect [33-36; 38-41].

Environmental exposure to Hg has also been shown to disrupt thyroid hormone homeostasis, particularly among individuals consuming fish from contaminated waters or those with occupational exposure [47-49]. Arsenic, especially in its inorganic and methylated forms, has demonstrated carcinogenic potential in the thyroid gland and may act as a cocarcinogen in genetically susceptible individuals [52; 53]. Increased Pb levels have been associated with thyroid dysfunction and an elevated risk of thyroid neoplasms, as confirmed in studies on occupational exposure and patient tissue analysis [54; 55]. Similarly, copper (hereinafter – Cu) and vanadium (hereinafter – V) have been implicated in thyroid carcinogenesis, with Cu influencing BRAF V600E tumor progression and vanadium compounds inducing inflammatory chemokine production in thyrocytes [56-61]. Altered concentrations of essential trace elements, including decreased selenium, magnesium, and zinc levels, have also been observed in thyroid cancer patients, further suggesting a role for trace element imbalance in thyroid tumorigenesis [56-58].

Particulate air pollution (PM2.5, PM10) increases the risk of thyroid malignancy by inducing inflammation and oxidative stress [11; 63]. Studies show that long-term exposure to these particles has been linked to a higher incidence of papillary thyroid carcinoma, especially with a 10 µg/m³ increase in PM2.5 concentration [62–69]. Prenatal exposure to PM2.5 and PM10 has also been associated with elevated total T4 levels in newborns, particularly during critical windows of pregnancy [65; 66].

Adverse technogenic factors have a predominant influence on the elemental status of populations working in hazardous industries or living near industrial enterprises, leading to maladaptation and a reduction in the functional reserves of the population, including due to trace element imbalances [25]. Results have also been obtained proving the impact of oil and gas extraction on the severity of iodine deficiency conditions in children. It has been noted that in regions with oil and gas industries, the content of manganese, boron, vanadium, and silicon in children's hair is much higher than in areas with favorable conditions. These elements can act as competitors to iodine in forming vital chemical bonds in the child's body [26].

Meanwhile, pesticides and chlorinated compounds further disrupt hormone synthesis, contributing to the development of carcinogenesis. Pesticides, such as DDT, lindane, atrazine, and malathion, disrupt thyroid hormone synthesis and function through multiple mechanisms, including inhibiting iodine uptake and altering thyroid gene expression, which may lead to abnormal thyroid tissue proliferation and oncogenesis [70-77]. Additionally, nitrate contamination in drinking water and nitrogen dioxide air pollution are linked to thyroid dysfunction and increased risk of hypothyroidism and congenital thyroid disorders, likely due to their endocrine-disrupting properties and promotion of oxidative stress [78-82].

Radiological contamination from nuclear accidents increases the prevalence of nodular thyroid disease and autoimmune thyroiditis due to the gland's vulnerability to ionizing radiation [67; 85; 87]. Our findings confirm the well-established sensitivity of the thyroid gland to ionizing radiation, a major environmental risk factor linked to thyroid dysfunction and carcinogenesis [83]. Exposure to radioactive iodine (131I), primarily from nuclear accidents and medical applications, has been strongly associated with increased incidence of papillary thyroid carcinoma, particularly in children and adolescents, as observed after the Chernobyl disaster [84-87]. Similar long-term effects have been reported in atomic bomb survivors, highlighting a dose-dependent increase in thyroid cancer risk with both acute and chronic radiation exposure [88-90]. In regions affected by nuclear testing and industrial pollution, such as Kazakhstan's Semipalatinsk area, chronic low-dose radiation exposure has led to significant thyroid pathology, including diffuse goiter, nodular formations, autoimmune thyroiditis, and a high prevalence of thyroid hypofunction [91-93].

Elevated radionuclide levels in drinking water correlate strongly with increased incidence of autoimmune thyroiditis and goiter among children, suggesting a direct link between environmental radiation burden and thyroid disease prevalence [95].

In summary, these findings highlight the complex interplay of hormonal, molecular, and immune disruptions caused by environmental contaminants on thyroid health, particularly during critical developmental periods [88; 91; 92]. For example, prenatal exposure to pollution lowers neonatal thyroxine levels, with possible neurodevelopmental effects [65; 66]. The combined effects of endemic iodine deficiency, goitrogens, and trace element imbalances emphasize the need to address both nutritional and environmental factors [1; 7; 30]. Given the variability in toxicokinetics and sex-specific responses to heavy metals, comprehensive, multidisciplinary research and coordinated public health strategies are essential to effectively prevent and manage thyroid diseases related to environmental exposures, ultimately protecting population health-especially in heavily polluted and radiation-affected areas.

Conclusion

Environmental factors, including air, soil, and water pollutants, climate change, endocrine disruptors, nutrients and food contaminants, and infectious agents, can significantly impact thyroid function. These pollutants disrupt thyroid hormone synthesis and regulation, metabolism, leading to conditions like hypothyroidism, hyperthyroidism, thyroid nodules, and autoimmune thyroid diseases. Environmental factors play a crucial role in thyroid development and function throughout life. However, there is insufficient understanding, especially regarding childhood influences and the mechanisms of various pollutants. Future studies should focus on the role of all environmental factors on thyroid function starting from pregnancy, as these will have effects throughout life. A multidisciplinary approach, involving endocrinologists, epidemiologists, toxicologists, and public health experts, is crucial for understanding the complex relationship between environmental factors and thyroid disease. These efforts will improve the prevention, early detection, and management of thyroid disorders, reducing their global prevalence and severity.

References

1. Yakubouski S. U., et al. Epidemiology of benign thyroid disorders in the adult population of the Republic of Belarus: Analysis of nationwide statistics 2009 to 2019 // Problems of Endocrinology. – 2022. – Vol. 68(3). – P. 30-43. – DOI 10.14341/probl12844.

2. Fitzgerald S. P., Bean, et al. Physiological linkage of thyroid and pituitary sensitivities // Endocrine. – 2023. – Vol. 79. – P. 143-151. – DOI 10.1007/s12020-022-03184-8.

3. Zbigniew S. Role of iodine in metabolism // Recent Patents on Endocrine, Metabolic & Immune

Drug Discovery. – 2017. – Vol. 10(2). – P. 123-126. – DOI 10.2174/1872214811666170119110618.
4. Toloza F. J. K., Mao Y., Menon L., George G. Association of thyroid function with suicidal behavior: A systematic review and meta-analysis // Medicina (Kaunas). – 2021. – Vol. 57(7). – P. 714. – DOI 10.3390/medicina57070714.
5. Yazbeck C. F., Sullivan S. D. Thyroid disorders during pregnancy // Medical Clinics of North America. – 2012. – Vol. 96(2). – P. 235-256. – DOI 10.1016/j.mcna.2012.01.004.
6. Danzi S., Klein I. Thyroid hormone and the cardiovascular system // Medical Clinics of North America. – 2012. – Vol. 96(2). – P. 257-268. – DOI 10.1016/j.mcna.2012.01.006.
7. Street M. E., et al. The impact of environmental factors and contaminants on thyroid function and disease from fetal to adult life: Current evidence and future directions // Frontiers in Endocrinology (Lausanne). – 2024. – Vol. 15. – Article No. 1429884. – DOI 10.3389/fendo.2024.1429884.
8. Zeng Y., et al. Climate and air pollution exposure are associated with thyroid function parameters: A retrospective cross-sectional study // Journal of Endocrinological Investigation. – 2021. – Vol. 44(7). – P. 1515-1523.
9. Vareda J. P., et al. Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review // Journal of Environmental Management. – 2019. – Vol. 246. – P. 101-118.
10. Hosseini M. J., et al. A worldwide systematic review, meta-analysis and meta-regression of nitrate and nitrite in vegetables and fruits // Ecotoxicology and Environmental Safety. – 2023. – Vol. 257. – Article No. 114934.
11. WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. – Geneva: WHO, 2021. – 219 p.
12. Benvenga S., et al. Endocrine disruptors and thyroid autoimmunity // Best Practice & Research Clinical Endocrinology & Metabolism. – 2020. – Vol. 34(1). – Article No. 101377. – DOI 10.1016/j.beem.2020.101377.
13. Pellegriti G., et al. Worldwide increasing incidence of thyroid cancer: Update on epidemiology and risk factors // Journal of Cancer Epidemiology. – 2013. – Vol. 965212.
14. Carlé A., et al. Epidemiology of nodular goitre: Influence of iodine intake // Best Practice & Research Clinical Endocrinology & Metabolism. – 2014. – Vol. 28(4). – C. 465-479.
15. Ferrari S. M., Fallahi P., et al. Environmental issues in thyroid diseases // Frontiers in Endocrinology (Lausanne). – 2017. – Vol. 8(50). – DOI 10.3389/fendo.2017.00050.
16. Kazakova M. P., Tskaeva A. A., Starostina E. A., Troshina E. A. Autoimmune thyroiditis – what's new? // Clinical and Experimental Thyroidology. – 2023. – Vol. 19(4). – C. 4-12.
17. Zimmermann M. B., Boelaert K. Iodine deficiency and thyroid disorders // The Lancet Diabetes & Endocrinology. – 2015. – Vol. 3(4). – C. 286-295. – DOI 10.1016/S2213-8587(14)70225-6.
18. Bekenov N., et al. Diffuse enlargement of the thyroid gland as a result of the impact of adverse factors on the pituitary-thyroid system of children // Bangladesh Journal of Medical Science. – 2024. – Vol. 23(4). – C. 1213-1218. – DOI 10.3329/bjms.v23i4.76539.
19. Troshina E. A., et al. Structural and morphologic characteristics of nodular goiter in chronic iodine deficiency status // Clinical and Experimental Thyroidology. – 2023. – Vol. 19(1). – C. 20-28.
20. Andersen S. L., Andersen S. Turning to thyroid disease in pregnant women // European Thyroid Journal. – 2020. – Vol. 9(5). – C. 2250233. – DOI 10.1159/000506228.
21. Henrichs J. et al. Maternal hypothyroxinemia and effects on cognitive functioning in childhood: how and why? // Clinical Endocrinology (Oxford). – 2013. – Vol. 79(2). – P. 152-162. – DOI: 10.1111/cen.12227.
22. Lundgaard M.H. et al. Maternal hypothyroidism and the risk of preeclampsia: a Danish national and regional study // Maternal Health, Neonatology and Perinatology. – 2024. – Vol. 10(1). – P. 16. – DOI: 10.1186/s40748-024-00181-3.
23. Ignatenko G.A. et al. The impact of environmental pollution on population health: the relationship between trace element imbalance and various cardiovascular pathologies: monograph. – Chita: Transbaikal State University, 2021. – 231 p.
24. Esposito D. et al. Influence of short-term selenium supplementation on the natural course of Hashimoto's thyroiditis: clinical results of a blinded placebo-controlled randomized prospective trial // Journal of Endocrinological Investigation. – 2017. – Vol. 40. – P. 83-89. – DOI: 10.1007/s40618-016-

0556-y.
25. Mamyrbaev A.A. et al. The content of metals in hair and blood in the child population of cities of Aktobe Region // Gigiena i Sanitariya. – 2012. – Vol. 3. – P. 61-62.
26. Kudabayeva Kh.I. et al. Role of trace elements imbalance in development of endemic goitre among schoolchildren in oil and gas districts of the western region of the Republic of Kazakhstan // Journal of Trace Elements in Medicine and Biology. – 2016. – Vol. 36. – P. 36-44. – DOI: 10.1016/j.jtemb.2016.03.006.
27. Vigneri R. et al. Heavy metals in the volcanic environment and thyroid cancer // Molecular and Cellular Endocrinology. – 2017. – Vol. 457. – P. 73-80. – DOI: 10.1016/j.mce.2016.10.027.
28. Kudabayeva Kh.I. et al. The problem of iodine deficiency disorders in the Republic of Kazakhstan // West Kazakhstan Medical Journal. – 2013. – Vol. 3 (39). – P. 18-23.
29. Vareda J.P., Valente A.J.M., Durães L. Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: a review // Journal of Environmental Management. – 2019. – Vol. 246. – P. 101-118. – DOI: 10.1016/j.jenvman.2019.05.126.
30. Savchenko O.V., Toupeleev P.A. Lead, cadmium, manganese, cobalt, zinc and copper levels in whole blood of urban teenagers with non-toxic diffuse goiter // International Journal of Environmental Health Research. – 2012. – Vol. 22(1). – P. 51-59. – DOI: 10.1080/09603123.2011.588324.
31. Malandrino P. et al. Increased thyroid cancer incidence in volcanic areas: a role of increased heavy metals in the environment? // International Journal of Molecular Sciences. – 2020. – Vol. 21(10). – P. 3425. – DOI: 10.3390/ijms21103425.
32. Malandrino P. et al. Concentration of metals and trace elements in the normal human and rat thyroid: comparison with muscle and adipose tissue and volcanic versus control areas // Thyroid. – 2019. – Vol. 30. – P. 290-299. – DOI: 10.1089/thy.2019.0244.
33. Buha A. et al. Overview of cadmium thyroid disrupting effects and mechanisms // International Journal of Molecular Sciences. – 2018. – Vol. 19(5). – P. 1501. – DOI: 10.3390/ijms19051501.
34. Klaassen C.D., Liu J., Diwan B.A. Metallothionein protection of cadmium toxicity // Toxicology and Applied Pharmacology. – 2009. – Vol. 238. – P. 215-220. – DOI: 10.1016/j.taap.2009.03.026.
35. Faroon O. et al. Toxicological profile for cadmium. – Atlanta (GA): Agency for Toxic Substances and Disease Registry (US), 2012. – September.
36. Jain R.B., Choi Y.S. Interacting effects of selected trace and toxic metals on thyroid function // International Journal of Environmental Health Research. – 2016. – Vol. 26. – P. 75-91. – DOI: 10.1080/09603123.2015.1020421.
37. Luo J., Hendryx M. Relationship between blood cadmium, lead, and serum thyroid measures in US adults (NHANES 2007–2010) // International Journal of Environmental Health Research. – 2014. – Vol. 24. – P. 125-136. – DOI: 10.1080/09603123.2013.800962.
38. Rosati M.V. et al. Correlation between urinary cadmium and thyroid hormones in outdoor workers exposed to urban stressors // Toxicology and Industrial Health. – 2016. – Vol. 32. – P. 1978-1986. – DOI: 10.1177/0748233715585588.
39. Jurdziak M. et al. Concentration of thyrotropic hormone in persons occupationally exposed to lead, cadmium and arsenic // Biological Trace Element Research. – 2018. – Vol. 182. – P. 196-203. – DOI: 10.1007/s12011-017-1088-5.
40. Nie X., Chen Y. et al. Lead and cadmium exposure, higher thyroid antibodies and thyroid dysfunction in Chinese women // Environmental Pollution. – 2017. – Vol. 230. – P. 320-328. – DOI: 10.1016/j.envpol.2017.06.050.
41. Rasic-Milutinovic Z. et al. Potential influence of selenium, copper, zinc and cadmium on L-thyroxine substitution in patients with Hashimoto thyroiditis and hypothyroidism // Experimental and Clinical Endocrinology & Diabetes. – 2017. – Vol. 125. – P. 79-85. – DOI: 10.1055/s-0042-116070.
42. Liu L. et al. Thyroid disruption and reduced mental development in children from an informal E-waste recycling area: a mediation analysis // Chemosphere. – 2018. – Vol. 193. – P. 498-505. – DOI: 10.1016/j.chemosphere.2017.11.031.
43. Bray F. et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries // CA: A Cancer Journal for Clinicians. – 2024. – Vol. 74(3). – P. 229-263. – DOI: 10.3322/caac.21834.
44. Zhang L. et al. Prioritizing of potential environmental exposure carcinogens beyond IARC group 1–2B based on weight of evidence (WoE) approach // Regulatory Toxicology and Pharmacology. –

2024. – Vol. 150. – Article No. 105646. – DOI: 10.1016/j.yrtph.2024.105646.

45. Rahib L. et al. Projecting cancer incidence and deaths to 2030: the unexpected burden of thyroid, liver, and pancreas cancers in the United States // Cancer Research. – 2014. – Vol. 74(11. – P. 2913-2921. – DOI: 10.1158/0008-5472.CAN-14-0155.

46. Park E. et al. Environmental exposure to cadmium and risk of thyroid cancer from national industrial complex areas: a population-based cohort study // Chemosphere. – 2021. – Vol. 268. – Article No. 128819. – DOI: 10.1016/j.chemosphere.2020.128819.

47. Falnoga I. et al. Mercury, selenium, and cadmium in human autopsy samples from Idrija residents and mercury mine workers // Environmental Research. – 2000. – Vol. 84. – P. 211-218. – DOI: 10.1006/enrs.2000.4112.

48. Chung H.K. et al. Some elements in thyroid tissue are associated with more advanced stage of thyroid cancer in Korean women // Biological Trace Element Research. – 2016. – Vol. 171. – P. 135-720. – DOI: 10.1007/s12011-015-0502-5.

49. Hu Q., Han X., Dong G. et al. Association between mercury exposure and thyroid hormones levels: a meta-analysis // Environmental Research. – 2021. – Vol. 196. – Article No. 110928. – DOI: 10.1016/j.envres.2020.110928.

50. Soldin O.P., Aschner M. Effects of manganese on thyroid hormone homeostasis: potential links // Neurotoxicology. – 2007. – Vol. 28. – P. 951-956. – DOI: 10.1016/j.neuro.2007.05.003.

51. Vargas A.C., et al. Exposure to common-use pesticides, manganese, lead, and thyroid function among pregnant women from the Infants' Environmental Health (ISA) study, Costa Rica // Science of the Total Environment. – 2021. – Vol. 810. – P. 151288. – DOI: 10.1016/j.scitotenv.2021.151288.

52. Sun H., et al. Mechanisms of arsenic disruption on gonadal, adrenal and thyroid endocrine systems in humans: A review // Environment International. – 2016. – Vol. 95. – P. 61-68.

53. Zidane M., et al. Non-Essential Trace Elements Dietary Exposure in French Polynesia: Intake Assessment, Nail Bio Monitoring and Thyroid Cancer Risk // Asian Pacific Journal of Cancer Prevention (APJCP). – 2019. – Vol. 20. – P. 355-367. – DOI: 10.31557/APJCP.2019.20.2.355.

54. Peng Xiaokun, et al. Effect of lead exposure on thyroid hormone levels in occupationally exposed populations: a Meta-analysis // Chinese Journal of Disease Control & Prevention. – 2024. – Vol. 28(7). – P. 856-863. – DOI: 10.16462/j.cnki.zhjbkz.2024.07.017.

55. Li H., et al. Correlation between serum lead and thyroid diseases: Papillary thyroid carcinoma, nodular goiter, and thyroid adenoma // International Journal of Environmental Health Research. – 2017. – Vol. 27. – P. 409-419.

56. Shen F., et al. The Association Between Serum Levels of Selenium, Copper, and Magnesium with Thyroid Cancer: a Meta-analysis // Biological Trace Element Research. – 2015. – Vol. 167(2). – P. 225-235. – DOI: 10.1007/s12011-015-0304-9.

57. Gumulec J., et al. Serum and tissue zinc in epithelial malignancies: a meta-analysis // PLoS One. – 2014. – Vol. 9(6). – Article No. 99790. – DOI: 10.1371/journal.pone.0099790.

58. Xu M., et al. Copper chelation as targeted therapy in a mouse model of oncogenic BRAF-driven papillary thyroid cancer // Clinical Cancer Research. – 2018. – Vol. 24. – P. 4271-4281.

59. van Gerwen M., Alerte E., et al. The role of heavy metals in thyroid cancer: A meta-analysis // Journal of Trace Elements in Medicine and Biology. – 2022. – Vol. 69. – P. 126900. – DOI: 10.1016/j.jtemb.2021.126900.

60. Luz A.L., Wu X. Toxicology of inorganic carcinogens // Advances in Molecular Toxicology. – 2018. – Vol. 12. – P. 1-46.

61. Fallahi P., et al. Vanadium pentoxide induces the secretion of CXCL9 and CXCL10 chemokines in thyroid cells // Oncology Reports. – 2018. – Vol. 39. – P. 2422-2426. – DOI: 10.3892/or.2018.6307.

62. Giannoula E., et al. Ecological study on thyroid cancer incidence and mortality in association with European Union member states' air pollution // International Journal of Environmental Research and Public Health. – 2020. – Vol. 18(1). – P. 153. – DOI: 10.3390/ijerph18010153.

63. Karzai S., et al. Ambient particulate matter air pollution is associated with increased risk of papillary thyroid cancer // Surgery. – 2021. – Article No. 0039-6060(21). – P. 415-423. – DOI: 10.1016/j.surg.2021.06.031.

64. Cong X. Air pollution from industrial waste gas emissions is associated with cancer incidences in Shanghai, China // Environmental Science and Pollution Research International. – 2018. – Vol. 25(13). – P. 13067-13078. – DOI: 10.1007/s11356-

018-1522-4.
65. Howe C.G., et al. Association of prenatal exposure to ambient and traffic-related air pollution with newborn thyroid function: Findings from the children's health study // JAMA Network Open. – 2018. – Vol. 1. – Article No. 182172. – DOI: 10.1001/jamanetworkopen.2018.2172.
66. Irizar A., et al. Association between prenatal exposure to air pollutants and newborn thyroxine (T4) levels // Environmental Research. – 2021. – Vol. 197. – Article No. 111132. – DOI: 10.1016/j.envres.2021.111132.
67. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation: UNSCEAR 2008 report to the General Assembly with Scientific Annexes. – New York: United Nations, 2011. – Vol. 1. – 313 p.
68. Marcello M.A., et al. The influence of the environment on the development of thyroid tumors: a new appraisal // Endocrine-Related Cancer. – 2014. – Vol. 21. – P. 235-254. – DOI: 10.1530/ERC-14-0057.
69. Sadeghi H., et al. Attributable risk fraction of four lifestyle risk factors of thyroid cancer: a meta-analysis // Journal of Public Health (Oxford). – 2018. – Vol. 40. – P. 91-98. – DOI: 10.1093/pubmed/fdx088.
70. Sirikul W., Sapbamrer R. Exposure to pesticides and the risk of hypothyroidism: a systematic review and meta-analysis // BMC Public Health. – 2023. – Vol. 23(1). – Article No. 1867. – DOI: 10.1186/s12889-023-16644-8.
71. Kruger E., et al. Thyroid carcinoma: A review for 25 years of environmental risk factors studies // Cancers (Basel). – 2022. – Vol. 14(24). – P. 6172. – DOI: 10.3390/cancers14246172.
72. Han M.A., Kim J.H., Song H.S. Persistent organic pollutants, pesticides, and the risk of thyroid cancer: Systematic review and meta-analysis // European Journal of Cancer Prevention. – 2019. – Vol. 28. – P. 344-349. – DOI: 10.1097/CEJ.0000000000000457.
73. Lerro C.C., et al. Pesticide exposure and incident thyroid cancer among male pesticide applicators in agricultural health study // Environment International. – 2020. – Vol. 146. – Article No. 106187. – DOI: 10.1016/j.envint.2020.106187.
74. Freeman L.E.B., et al. Atrazine and cancer incidence among pesticide applicators in the Agricultural Health Study (1994-2007) // Environmental Health Perspectives. – 2011. – Vol. 119. – P. 1253-1259. – DOI: 10.1289/ehp.1103561.
75. Zeng F., et al. Occupational exposure to pesticides and other biocides and risk of thyroid cancer // Occupational and Environmental Medicine. – 2017. – Vol. 74. – P. 502-510. – DOI: 10.1136/oemed-2016-103931.
76. Lerro C.C., et al. Pesticide exposure and incident thyroid cancer among male pesticide applicators in agricultural health study // Environment International. – 2020. – Vol. 146. – P. 106187. – DOI: 10.1016/j.envint.2020.106187.
77. Lerro C.C., et al. A nested case-control study of polychlorinated biphenyls, organochlorine pesticides, and thyroid cancer in the Janus Serum Bank cohort // Environmental Research. – 2018. – Vol. 165. – P. 125-132. – DOI: 10.1016/j.envres.2018.04.012.
78. Zendehbad M., et al. Nitrate in groundwater and agricultural products: intake and risk assessment in northeastern Iran // Environmental Science and Pollution Research International. – 2022. – Vol. 29. – P. 78603-78619.
79. Park S.J., et al. National cohort and meteorological data-based nested case-control study on the association between air pollution exposure and thyroid cancer // Scientific Reports. – 2021. – Vol. 11(1). – Article No. 21562. – DOI: 10.1038/s41598-021-00882-7.
80. Qi C., et al. Maternal exposure to O_3 and NO_2 may increase the risk of newborn congenital hypothyroidism: a national data-based analysis in China // Environmental Science and Pollution Research International. – 2021. – Vol. 28. – P. 34621-34629. – DOI: 10.1007/s11356-021-13083-6.
81. California Office of Environmental Health Hazard Assessment (OEHHA). Nitrate and Nitrite in Drinking Water. – Sacramento, CA, 2018.
82. Drozd V.M., Saenko V.A., et al. Major factors affecting incidence of childhood thyroid cancer in Belarus after the Chernobyl accident: Do nitrates in drinking water play a role? // PLoS One. – 2015. – Vol. 10(9). – Article No. 0137226. – DOI: 10.1371/journal.pone.0137226.
83. Yamamoto H., Hayashi K., Scherb H. Association between the detection rate of thyroid cancer and the external radiation dose-rate after the nuclear power plant accidents in Fukushima, Japan // Medicine. – 2019. – Vol. 98. – Article No. 17165.

– DOI: 10.1097/md.0000000000017165.
84. Winder M., et al. The impact of iodine concentration disorders on health and cancer // Nutrients. – 2022. – Vol. 14. – P. 2209. – DOI: 10.3390/nu14112209.
85. Weiss W. Chernobyl thyroid cancer: 30 years of follow-up overview // Radiation Protection Dosimetry. – 2018. – Vol. 182. – P. 58-61. – DOI: 10.1093/rpd/ncy147.
86. McCall C. Chernobyl disaster 30 years on: Lessons not learned // The Lancet. – 2016. – Vol. 387. – P. 1707-1708.
87. Ivanov V.K., et al. Radiation-epidemiological studies of thyroid cancer incidence in Russia after the Chernobyl accident (estimation of radiation risks, 1991–2008 follow-up period) // Radiation Protection Dosimetry. – 2012. – Vol. 151. – P. 489-499. – DOI: 10.1093/rpd/ncs019.
88. Suzuki K., et al. Radiation-induced thyroid cancers: Overview of molecular signatures // Cancers (Basel). – 2019. – Vol. 11. – P. 1109-1290. – DOI: 10.3390/cancers11091290.
89. Little M.P., et al. Age effects on radiation response: Summary of a recent symposium and future perspectives // International Journal of Radiation Biology. – 2022. – Vol. 98. – P. 1673-1683.
90. Yamashita S., et al. Radiation exposure and thyroid cancer risk after the Fukushima nuclear power plant accident in comparison with the Chernobyl accident // Radiation Protection Dosimetry. – 2016. – Vol. 171. – P. 41-46. – DOI: 10.1093/rpd/ncw189.
91. Manatova A.M. Assessment of violations of nonspecific resistance and psychological status in descendants of persons exposed to radiation: Dissertation for the degree of Doctor of Philosophy (PhD). – Semey, 2020.
92. Bauer S., Gusev B., et al. The Legacies of Soviet Nuclear Testing in Kazakhstan: Fallout, Public Health and Societal Issues. Radioactivity in the Environment. – 2013. – Vol. 19. – P. 241-258.
93. Espenbetova M. Zh., Zamanbekova Zh. K., et al. Condition of the thyroid gland at the population of the areas adjacent to the former Semipalatinsk nuclear test site // Science and Healthcare. – 2014. – Vol. 5. – P. 28-32.
94. Malenchenko A. F., et al. Biological action of natural uranium on the thyroid gland // Astrakhan Medical Journal. – 2012. – Vol. 4. – P. 174-176.
95. Toychuyeva G. The effects of radionuclide factors on the development of autoimmune thyroiditis in senior children // Chemical Safety Science. – 2021. – Vol. 5. – P. 240-251. – DOI: 10.25514/CHS.2021.2.20015.

References

1. Yakubouski, S. U., et al. (2022). Epidemiology of benign thyroid disorders in the adult population of the Republic of Belarus: Analysis of nationwide statistics 2009-2019. Problems of Endocrinology, 68(3), 30-43. DOI: https://doi.org/10.14341/probl12844.
2. Fitzgerald, S. P., Bean, et al. (2023). Physiological linkage of thyroid and pituitary sensitivities. Endocrine, 79, 143-151. DOI: https://doi.org/10.1007/s12020-022-03184-8.
3. Zbigniew, S. (2017). Role of iodine in metabolism. Recent Patents on Endocrine, Metabolic & Immune Drug Discovery, 10(2), 123-126. DOI: https://doi.org/10.2174/1872214811666170119110618.
4. Toloza, F. J. K., Mao, Y., Menon, L., & George, G. (2021). Association of thyroid function with suicidal behavior: A systematic review and meta-analysis. Medicina (Kaunas), 57(7), 714. DOI: https://doi.org/10.3390/medicina57070714.
5. Yazbeck, C. F., & Sullivan, S. D. (2012). Thyroid disorders during pregnancy. Medical Clinics of North America, 96(2), 235-256. DOI: https://doi.org/10.1016/j.mcna.2012.01.004.
6. Danzi, S., & Klein, I. (2012). Thyroid hormone and the cardiovascular system. Medical Clinics of North America, 96(2), 257-268. DOI: https://doi.org/10.1016/j.mcna.2012.01.006.
7. Street, M. E., et al. (2024). The impact of environmental factors and contaminants on thyroid function and disease from fetal to adult life: Current evidence and future directions. Frontiers in Endocrinology (Lausanne), 15, Article 1429884. DOI: https://doi.org/10.3389/fendo.2024.1429884.
8. Zeng, Y., et al. (2021). Climate and air pollution exposure are associated with thyroid function parameters: A retrospective cross-sectional study. Journal of Endocrinological Investigation, 44(7), 1515-1523.
9. Vareda, J. P., et al. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. Journal of Environmental Management, 246, 101-118.
10. Hosseini, M. J., et al. (2023). A worldwide systematic review, meta-analysis and meta-regression

of nitrate and nitrite in vegetables and fruits. Ecotoxicology and Environmental Safety, 257, Article 114934.

11. World Health Organization. (2021). WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (p. 219). Geneva: WHO.

12. Benvenga, S., et al. (2020). Endocrine disruptors and thyroid autoimmunity. Best Practice & Research Clinical Endocrinology & Metabolism, 34(1), Article 101377. DOI: https://doi.org/10.1016/j.beem.2020.101377.

13. Pellegriti, G., et al. (2013). Worldwide increasing incidence of thyroid cancer: Update on epidemiology and risk factors. Journal of Cancer Epidemiology, 2013, Article 965212.

14. Carlé, A., et al. (2014). Epidemiology of nodular goitre: Influence of iodine intake. Best Practice & Research Clinical Endocrinology & Metabolism, 28(4), 465-479.

15. Ferrari, S. M., & Fallahi, P., et al. (2017). Environmental issues in thyroid diseases. Frontiers in Endocrinology (Lausanne), 8(50). DOI: https://doi.org/10.3389/fendo.2017.00050.

16. Kazakova, M. P., Tskaeva, A. A., Starostina, E. A., & Troshina, E. A. (2023). Autoimmune thyroiditis – what's new? Clinical and Experimental Thyroidology, 19(4), 4-12.

17. Zimmermann, M. B., & Boelaert, K. (2015). Iodine deficiency and thyroid disorders. The Lancet Diabetes & Endocrinology, 3(4), 286-295. DOI: https://doi.org/10.1016/S2213-8587(14)70225-6.

18. Bekenov, N., et al. (2024). Diffuse enlargement of the thyroid gland as a result of the impact of adverse factors on the pituitary-thyroid system of children. Bangladesh Journal of Medical Science, 23(4), 1213-1218. DOI: https://doi.org/10.3329/bjms.v23i4.76539.

19. Troshina, E. A., et al. (2023). Structural and morphologic characteristics of nodular goiter in chronic iodine deficiency status. Clinical and Experimental Thyroidology, 19(1), 20-28.

20. Andersen, S. L., & Andersen, S. (2020). Turning to thyroid disease in pregnant women. European Thyroid Journal, 9(5), 2250233. DOI: https://doi.org/10.1159/000506228.

21. Henrichs, J., et al. (2013). Maternal hypothyroxinemia and effects on cognitive functioning in childhood: How and why? Clinical Endocrinology (Oxford), 79(2), 152-162. DOI: https://doi.org/10.1111/cen.12227.

22. Lundgaard, M. H., et al. (2024). Maternal hypothyroidism and the risk of preeclampsia: A Danish national and regional study. Maternal Health, Neonatology and Perinatology, 10(1), 16. DOI: https://doi.org/10.1186/s40748-024-00181-3.

23. Ignatenko, G. A., et al. (2021). The impact of environmental pollution on population health: The relationship between trace element imbalance and various cardiovascular pathologies (Monograph). Chita: Transbaikal State University.

24. Esposito, D., et al. (2017). Influence of short-term selenium supplementation on the natural course of Hashimoto's thyroiditis: Clinical results of a blinded placebo-controlled randomized prospective trial. Journal of Endocrinological Investigation, 40, 83–89. DOI: https://doi.org/10.1007/s40618-016-0556-y.

25. Mamyrbaev, A. A., et al. (2012). The content of metals in hair and blood in the child population of cities of Aktobe Region. Gigiena i Sanitariya, 3, 61-62.

26. Kudabayeva, Kh. I., et al. (2016). Role of trace elements imbalance in development of endemic goitre among schoolchildren in oil and gas districts of the western region of the Republic of Kazakhstan. Journal of Trace Elements in Medicine and Biology, 36, 36-44. DOI: https://doi.org/10.1016/j.jtemb.2016.03.006.

27. Vigneri, R., et al. (2017). Heavy metals in the volcanic environment and thyroid cancer. Molecular and Cellular Endocrinology, 457, 73-80. DOI: https://doi.org/10.1016/j.mce.2016.10.027.

28. Kudabayeva, Kh. I., et al. (2013). The problem of iodine deficiency disorders in the Republic of Kazakhstan. West Kazakhstan Medical Journal, 3(39), 18-23.

29. Vareda, J. P., Valente, A. J. M., & Durães, L. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. Journal of Environmental Management, 246, 101-118. DOI: https://doi.org/10.1016/j.jenvman.2019.05.126.

30. Savchenko, O. V., & Toupeleev, P. A. (2012). Lead, cadmium, manganese, cobalt, zinc and copper levels in whole blood of urban teenagers with non-toxic diffuse goiter. International Journal of Environmental Health Research, 22(1), 51-59. DOI: https://doi.org/10.1080/09603123.2011.588324.

31. Malandrino, P., et al. (2020). Increased thyroid cancer incidence in volcanic areas: A role of increased heavy metals in the environment? International Journal of Molecular Sciences, 21(10), 3425. DOI: https://doi.org/10.3390/ijms21103425.

32. Malandrino, P., et al. (2019). Concentration of metals and trace elements in the normal human and rat thyroid: Comparison with muscle and adipose tissue and volcanic versus control areas. Thyroid, 30, 290-299. DOI: https://doi.org/10.1089/thy.2019.0244.

33. Buha, A., et al. (2018). Overview of cadmium thyroid disrupting effects and mechanisms. International Journal of Molecular Sciences, 19(5), 1501. DOI: https://doi.org/10.3390/ijms19051501.

34. Klaassen, C. D., Liu, J., & Diwan, B. A. (2009). Metallothionein protection of cadmium toxicity. Toxicology and Applied Pharmacology, 238, 215-220. DOI: https://doi.org/10.1016/j.taap.2009.03.026.

35. Faroon, O., et al. (2012). Toxicological profile for cadmium. Atlanta, GA: Agency for Toxic Substances and Disease Registry (US).

36. Jain, R. B., & Choi, Y. S. (2016). Interacting effects of selected trace and toxic metals on thyroid function. International Journal of Environmental Health Research, 26, 75-91. DOI: https://doi.org/10.1080/09603123.2015.1020421.

37. Luo, J., & Hendryx, M. (2014). Relationship between blood cadmium, lead, and serum thyroid measures in US adults (NHANES 2007–2010). International Journal of Environmental Health Research, 24, 125-136. DOI: https://doi.org/10.1080/09603123.2013.800962.

38. Rosati, M. V., et al. (2016). Correlation between urinary cadmium and thyroid hormones in outdoor workers exposed to urban stressors. Toxicology and Industrial Health, 32, 1978-1986. DOI: https://doi.org/10.1177/0748233715585588.

39. Jurdziak, M., et al. (2018). Concentration of thyrotropic hormone in persons occupationally exposed to lead, cadmium and arsenic. Biological Trace Element Research, 182, 196-203. DOI: https://doi.org/10.1007/s12011-017-1088-5.

40. Nie, X., Chen, Y., et al. (2017). Lead and cadmium exposure, higher thyroid antibodies and thyroid dysfunction in Chinese women. Environmental Pollution, 230, 320-328. DOI: https://doi.org/10.1016/j.envpol.2017.06.050.

41. Rasic-Milutinovic, Z., et al. (2017). Potential influence of selenium, copper, zinc and cadmium on L-thyroxine substitution in patients with Hashimoto thyroiditis and hypothyroidism. Experimental and Clinical Endocrinology & Diabetes, 125, 79-85. DOI: https://doi.org/10.1055/s-0042-116070.

42. Liu, L., et al. (2018). Thyroid disruption and reduced mental development in children from an informal E-waste recycling area: A mediation analysis. Chemosphere, 193, 498-505. DOI: https://doi.org/10.1016/j.chemosphere.2017.11.031.

43. Bray, F., et al. (2024). Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: A Cancer Journal for Clinicians, 74(3), 229-263. DOI: https://doi.org/10.3322/caac.21834.

44. Zhang, L., et al. (2024). Prioritizing of potential environmental exposure carcinogens beyond IARC group 1-2B based on weight of evidence (WoE) approach. Regulatory Toxicology and Pharmacology, 150, Article 105646. DOI: https://doi.org/10.1016/j.yrtph.2024.105646.

45. Rahib, L., et al. (2014). Projecting cancer incidence and deaths to 2030: The unexpected burden of thyroid, liver, and pancreas cancers in the United States. Cancer Research, 74(11), 2913-2921. DOI: https://doi.org/10.1158/0008-5472.CAN-14-0155.

46. Park, E., et al. (2021). Environmental exposure to cadmium and risk of thyroid cancer from national industrial complex areas: A population-based cohort study. Chemosphere, 268, Article 128819. DOI: https://doi.org/10.1016/j.chemosphere.2020.128819.

47. Falnoga, I., et al. (2000). Mercury, selenium, and cadmium in human autopsy samples from Idrija residents and mercury mine workers. Environmental Research, 84, 211-218. DOI: https://doi.org/10.1006/enrs.2000.4112.

48. Chung, H. K., et al. (2016). Some elements in thyroid tissue are associated with more advanced stage of thyroid cancer in Korean women. Biological Trace Element Research, 171, 135-1720. DOI: https://doi.org/10.1007/s12011-015-0502-5.

49. Hu, Q., Han, X., Dong, G., et al. (2021). Association between mercury exposure and thyroid hormones levels: A meta-analysis. Environmental Research, 196, Article 110928. https://doi.org/10.1016/j.envres.2020.110928.

50. Soldin, O. P., & Aschner, M. (2007). Effects of manganese on thyroid hormone homeostasis: Potential links. Neurotoxicology, 28, 951-956. DOI:

https://doi.org/10.1016/j.neuro.2007.05.003.
51. Vargas, A. C., et al. (2021). Exposure to common-use pesticides, manganese, lead, and thyroid function among pregnant women from the Infants' Environmental Health (ISA) study, Costa Rica. Science of the Total Environment, 810, 151288. DOI: https://doi.org/10.1016/j.scitotenv.2021.151288.
52. Sun, H., et al. (2016). Mechanisms of arsenic disruption on gonadal, adrenal and thyroid endocrine systems in humans: A review. Environment International, 95, 61-68.
53. Zidane, M., et al. (2019). Non-essential trace elements dietary exposure in French Polynesia: Intake assessment, nail biomonitoring and thyroid cancer risk. Asian Pacific Journal of Cancer Prevention, 20, 355-367. DOI: https://doi.org/10.31557/APJCP.2019.20.2.355.
54. Peng, X., et al. (2024). Effect of lead exposure on thyroid hormone levels in occupationally exposed populations: A meta-analysis. Chinese Journal of Disease Control & Prevention, 28(7), 856-863. DOI: https://doi.org/10.16462/j.cnki.zhjbkz.2024.07.017.
55. Li, H., et al. (2017). Correlation between serum lead and thyroid diseases: Papillary thyroid carcinoma, nodular goiter, and thyroid adenoma. International Journal of Environmental Health Research, 27, 409-419.
56. Shen, F., et al. (2015). The association between serum levels of selenium, copper, and magnesium with thyroid cancer: A meta-analysis. Biological Trace Element Research, 167(2), 225-235. DOI: https://doi.org/10.1007/s12011-015-0304-9.
57. Gumulec, J., et al. (2014). Serum and tissue zinc in epithelial malignancies: A meta-analysis. PLoS ONE, 9(6), Article e99790. DOI: https://doi.org/10.1371/journal.pone.0099790.
58. Xu, M., et al. (2018). Copper chelation as targeted therapy in a mouse model of oncogenic BRAF-driven papillary thyroid cancer. Clinical Cancer Research, 24, 4271-4281.
59. van Gerwen, M., Alerte, E., et al. (2022). The role of heavy metals in thyroid cancer: A meta-analysis. Journal of Trace Elements in Medicine and Biology, 69, 126900. DOI: https://doi.org/10.1016/j.jtemb.2021.126900.
60. Luz, A. L., & Wu, X. (2018). Toxicology of inorganic carcinogens. Advances in Molecular Toxicology, 12, 1-46.
61. Fallahi, P., Mazzi, V., Vita, R., Ferrari, S. M., & Antonelli, A. (2018). Vanadium pentoxide induces the secretion of CXCL9 and CXCL10 chemokines in thyroid cells. Oncology Reports, 39(5), 2422-2426. DOI: https://doi.org/10.3892/or.2018.6307.
62. Giannoula, E., Tzanetakou, I., Georgakopoulos, P., & Evangelopoulos, A. (2020). Ecological study on thyroid cancer incidence and mortality in association with European Union member states' air pollution. International Journal of Environmental Research and Public Health, 18(1), 153. DOI: https://doi.org/10.3390/ijerph18010153.
63. Karzai, S., Li, X., Jung, S. H., et al. (2021). Ambient particulate matter air pollution is associated with increased risk of papillary thyroid cancer. Surgery, 169(3), 415-423. DOI: https://doi.org/10.1016/j.surg.2021.06.031.
64. Cong, X. (2018). Air pollution from industrial waste gas emissions is associated with cancer incidences in Shanghai, China. Environmental Science and Pollution Research International, 25(13), 13067-13078. DOI: https://doi.org/10.1007/s11356-018-1522-4.
65. Howe, C. G., Eckel, S. P., Habre, R., et al. (2018). Association of prenatal exposure to ambient and traffic-related air pollution with newborn thyroid function: Findings from the Children's Health Study. JAMA Network Open, 1(5), e182172. DOI: https://doi.org/10.1001/jamanetworkopen.2018.2172.
66. Irizar, A., Goñi, F., Lopez-Espinosa, M. J., et al. (2021). Association between prenatal exposure to air pollutants and newborn thyroxine (T4) levels. Environmental Research, 197, 111132. DOI: https://doi.org/10.1016/j.envres.2021.111132.
67. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2011). Sources and effects of ionizing radiation: UNSCEAR 2008 report to the General Assembly with scientific annexes (Vol. 1). United Nations.
68. Marcello, M. A., Malandrino, P., Almeida, J. F., et al. (2014). The influence of the environment on the development of thyroid tumors: A new appraisal. Endocrine-Related Cancer, 21(5), 235-254. DOI: https://doi.org/10.1530/ERC-14-0057.
69. Sadeghi, H., Khosravi, A., & Rezaei, N. (2018). Attributable risk fraction of four lifestyle risk factors of thyroid cancer: A meta-analysis. Journal of Public Health (Oxford), 40(1), 91-98. DOI: https://doi.org/10.1093/pubmed/fdx088.
70. Sirikul, W., & Sapbamrer, R. (2023). Exposure

to pesticides and the risk of hypothyroidism: A systematic review and meta-analysis. BMC Public Health, 23(1), 1867. DOI: https://doi.org/10.1186/s12889-023-16644-8.

71. Kruger, E., Piekarski, F., & Hansen, S. (2022). Thyroid carcinoma: A review for 25 years of environmental risk factors studies. Cancers (Basel), 14(24), 6172. DOI: https://doi.org/10.3390/cancers14246172.

72. Han, M. A., Kim, J. H., & Song, H. S. (2019). Persistent organic pollutants, pesticides, and the risk of thyroid cancer: Systematic review and meta-analysis. European Journal of Cancer Prevention, 28(4), 344-349. DOI: https://doi.org/10.1097/CEJ.0000000000000457.

73. Lerro, C. C., Koutros, S., Andreotti, G., et al. (2020). Pesticide exposure and incident thyroid cancer among male pesticide applicators in Agricultural Health Study. Environment International, 146, 106187. DOI: https://doi.org/10.1016/j.envint.2020.106187.

74. Freeman, L. E. B., Rusiecki, J. A., Hoppin, J. A., et al. (2011). Atrazine and cancer incidence among pesticide applicators in the Agricultural Health Study (1994–2007). Environmental Health Perspectives, 119(9), 1253-1259. DOI: https://doi.org/10.1289/ehp.1103561.

75. Zeng, F., Lerro, C. C., Lavoué, J., et al. (2017). Occupational exposure to pesticides and other biocides and risk of thyroid cancer. Occupational and Environmental Medicine, 74(7), 502-510. DOI: https://doi.org/10.1136/oemed-2016-103931.

76. Lerro, C. C., Koutros, S., Andreotti, G., et al. (2020). Pesticide exposure and incident thyroid cancer among male pesticide applicators in Agricultural Health Study. Environment International, 146, 106187. DOI: https://doi.org/10.1016/j.envint.2020.106187.

77. Lerro, C. C., Kjaerheim, K., et al. (2018). A nested case-control study of polychlorinated biphenyls, organochlorine pesticides, and thyroid cancer in the Janus Serum Bank cohort. Environmental Research, 165, 125-132. DOI: https://doi.org/10.1016/j.envres.2018.04.012.

78. Zendehbad, M., Khorasani, N., et al. (2022). Nitrate in groundwater and agricultural products: Intake and risk assessment in northeastern Iran. Environmental Science and Pollution Research International, 29(54), 78603-78619.

79. Park, S. J., Lee, J., Kim, S., et al. (2021). National cohort and meteorological data-based nested case-control study on the association between air pollution exposure and thyroid cancer. Scientific Reports, 11(1), 21562. DOI: https://doi.org/10.1038/s41598-021-00882-7.

80. Qi, C., Li, L., Zhang, Y., et al. (2021). Maternal exposure to O_3 and NO_2 may increase the risk of newborn congenital hypothyroidism: A national data-based analysis in China. Environmental Science and Pollution Research International, 28(27), 34621-34629. DOI: https://doi.org/10.1007/s11356-021-13083-6.

81. California Office of Environmental Health Hazard Assessment (OEHHA). (2018). Nitrate and nitrite in drinking water. Sacramento, CA: OEHHA.

82. Drozd, V. M., Saenko, V. A., et al. (2015). Major factors affecting incidence of childhood thyroid cancer in Belarus after the Chernobyl accident: Do nitrates in drinking water play a role? PLoS One, 10(9), e0137226. DOI: https://doi.org/10.1371/journal.pone.0137226.

83. Yamamoto, H., Hayashi, K., & Scherb, H. (2019). Association between the detection rate of thyroid cancer and the external radiation dose-rate after the nuclear power plant accidents in Fukushima, Japan. Medicine, 98(39), e17165. DOI: https://doi.org/10.1097/md.0000000000017165.

84. Winder, M., Schümann, D., & Herter, C. (2022). The impact of iodine concentration disorders on health and cancer. Nutrients, 14(11), 2209. DOI: https://doi.org/10.3390/nu14112209.

85. Weiss, W. (2018). Chernobyl thyroid cancer: 30 years of follow-up overview. Radiation Protection Dosimetry, 182(1), 58-61. DOI: https://doi.org/10.1093/rpd/ncy147.

86. McCall, C. (2016). Chernobyl disaster 30 years on: Lessons not learned. The Lancet, 387(10031), 1707-1708. DOI: https://doi.org/10.1016/S0140-6736(16)30257-1.

87. Ivanov, V. K., Kashcheev, V. V., Chekin, S. Y., et al. (2012). Radiation-epidemiological studies of thyroid cancer incidence in Russia after the Chernobyl accident (estimation of radiation risks, 1991-2008 follow-up period). Radiation Protection Dosimetry, 151(3), 489-499. DOI: https://doi.org/10.1093/rpd/ncs019.

88. Suzuki, K., Yamashita, S., & Mitsutake, N. (2019). Radiation-induced thyroid cancers: Overview of molecular signatures. Cancers (Basel), 11(9), 1290. DOI: https://doi.org/10.3390/can-

cers11091290.
89. Little, M. P., Shore, R., & Boice, J. D. (2022). Age effects on radiation response: Summary of a recent symposium and future perspectives. International Journal of Radiation Biology, 98(11), 1673-1683. DOI: https://doi.org/10.1080/09553002.2022.2067012.
90. Yamashita, S., Suzuki, S., Suzuki, K., & Shimura, H. (2016). Radiation exposure and thyroid cancer risk after the Fukushima nuclear power plant accident in comparison with the Chernobyl accident. Radiation Protection Dosimetry, 171(1), 41-46. DOI: https://doi.org/10.1093/rpd/ncw189.
91. Manatova, A. M. (2020). Assessment of violations of nonspecific resistance and psychological status in descendants of persons exposed to radiation (Doctoral dissertation). Semey State Medical University.
92. Bauer, S., Gusev, B., & Shchukina, N. (2013). The legacies of Soviet nuclear testing in Kazakhstan: Fallout, public health and societal issues. Radioactivity in the Environment, 19, 241-258.
93. Espenbetova, M. Zh., Zamanbekova, Zh. K., et al. (2014). Condition of the thyroid gland in the population of areas adjacent to the former Semipalatinsk nuclear test site. Science and Healthcare, 5, 28-32.
94. Malenchenko, A. F., Zlobina, L. A., & Sidorova, N. I. (2012). Biological action of natural uranium on the thyroid gland. Astrakhan Medical Journal, 4, 174-176.
95. Toychuyeva, G. (2021). The effects of radionuclide factors on the development of autoimmune thyroiditis in senior children. Chemical Safety Science, 5, 240-251. DOI: https://doi.org/10.25514/CHS.2021.2.20015.

ҚОРШАҒАН ОРТАДАҒЫ ҚОЛАЙСЫЗ ФАКТОРЛАРДЫҢ ХАЛЫҚ АРАСЫНДА ҚАЛҚАНША БЕЗІ ПАТОЛОГИЯСЫНЫҢ ДАМУ ЖИІЛІГІНЕ ӘСЕРІ

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Аңдатпа

Қалқанша без аурулары ішкі және сыртқы факторлардың әсерінен дамиды. Қоршаған орта мен радиациялық жағдайлардың өзгеруі қалқанша безі ауруларының таралуы мен сипатының өзгеруіне әкеледі. Бұл шолу қоршаған орта әсерінің қалқанша бездің құрылымы мен қызметіне ықпалын көрсетіп, соңғы ғылыми жаңалықтар мен механизмдерді сипаттайды және қосымша зерттеуді қажет ететін бағыттарды айқындайды.

Зерттеудің мақсаты. Қоршаған ортадағы қолайсыз өндірістік факторлардың қалқанша безінің қызметіне әсерін зерттейтін ғылыми деректерді талдау.

Материалдар мен әдістер. Іздеу PubMed, Web of Science, Scopus сынды электронды дерекқорларда сәйкес терминдер мен кілт сөздер арқылы жүргізілді. Зерттеуге қоршаған ортадағы зиянды факторлардың қалқанша безінің патологиясының пайда болуына әсерін зерттейтін түпнұсқа бақылау нәтижелері енгізілді.

Нәтижелер. Ауыр металдардың (Pb, Hg, Cd, As) жоғары деңгейі қалқанша без обырының даму қаупін арттырады. Мұнай-газ өңірлерінде балалардың шаш құрамында марганец, бор, ванадий және кремнийдің жоғары мөлшері анықталып, бұл йодтың сіңуін бұзып, йод тапшылығын туғызады. Кадмий тиреотроптық гормон деңгейін төмендетіп, гипертиреоздың дамуына ықпал етеді. Радиацияға ұшыраған аймақтарда (мысалы, Чернобыль, Семей) қалқанша без түйіндерінің және аутоиммундық тиреоидиттің жиілігі жоғары. Ұсақ қатты бөлшектер (PM2.5, PM10) қалқанша без обырының қаупін арттырады, ал жүкті әйелдердің ауаның ластануына ұшырауы жаңа туған нәрестелерде Т4 деңгейінің өзгеруіне әкеледі. Органикалық және бейорганикалық ластағыштар қалқанша без гормондарының түзілуін бұзып, обыр дамуын қоздырады.

Қорытынды. Экологиялық ластаушылар, оның ішінде ауыр металдар, радиацияның әсері, өнеркәсіптік қалдықтар мен ластаушылар, эндокриндік жүйенің жұмысына әсер ететін химиялық заттар қалқанша безінің ауруларының пайда болуы мен дамуына айтарлықтай рөл атқарады.

Түйін сөздер: *Қалқанша безінің дисфункциясы, эндокринді зақымдаушылар, қоршаған орта әсері.*

ВЛИЯНИЕ НЕБЛАГОПРИЯТНЫХ ФАКТОРОВ ОКРУЖАЮЩЕЙ СРЕДЫ НА ЧАСТОТУ ВОЗНИКНОВЕНИЯ ПАТОЛОГИИ ЩИТОВИДНОЙ ЖЕЛЕЗЫ СРЕДИ НАСЕЛЕНИЯ

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Аннотация

Заболевания щитовидной железы возникают как из-за внутренних, так и из-за внешних факторов. Изменяющиеся экологические и радиационные условия способствуют росту распространенности и изменению характера заболеваний щитовидной железы. В этом обзоре представлены современные данные о том, как внешние воздействия влияют на структуру и функцию щитовидной железы, включая недавние открытия, механизмы и области, требующие дальнейших исследований.

Цель исследования. Анализ научных источников, которые рассматривают влияние неблагоприятных производственных факторов окружающей среды на функционирование щитовидной железы.

Материалы и методы. Поиск исследований был проведён в электронных базах данных PubMed, Web of Science и Scopus с использованием соответствующих терминов и ключевых слов. Включены только оригинальные наблюдательные исследования, изучающие воздействие вредных факторов окружающей среды на возникновение патологий щитовидной железы.

Результаты. Высокие уровни тяжёлых металлов (Pb, Hg, Cd, As) связаны с повышенным риском рака щитовидной железы. В нефтегазовых регионах у детей выявляется повышенное содержание марганца, бора, ванадия и кремния в волосах, что нарушает усвоение йода и вызывает йододефицит. Кадмий снижает уровень тиреотропного гормона, способствуя развитию гипертиреоза. В районах, подвергшихся радиационному воздействию (например, Чернобыль, Семей), чаще наблюдаются узловые образования и аутоиммунный тиреоидит. Мелкие твердые частицы (PM2.5, PM10) повышают риск рака щитовидной железы, а воздействие загрязнённого воздуха во время беременности изменяет уровень Т4 у новорождённых.

Выводы. Экологические загрязнители, включая тяжёлые металлы, воздействие радиации, промышленные отходы и загрязнители, химические вещества, нарушающие работу эндокринной системы, играют значительную роль в возникновении и прогрессировании заболеваний щитовидной железы. Рост хронических заболеваний, в том числе патологий щитовидной железы, служит маркером экологического загрязнения.

Ключевые слова: *дисфункция щитовидной железы, эндокринные разрушители, воздействие окружающей среды.*

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