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ORIGINAL RESEARCH ARTICLE

Relationships between iodine and some trace elements in normal thyroid of females investigated by neutron activation analysis

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ABSTRACT

Thyroid diseases rank second among endocrine disorders, and prevalence of the diseases is higher in the elderly as compared to the younger population. An excess or deficiency of trace element contents in thyroid play important role in goitro- and carcinogenesis of gland. The correlations with age of the ten trace element (TE) contents (Ag, Co, Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn), I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn content ratios, and inter relationships between TE contents and I/TE content ratios in normal thyroid of 33 females (age range 3.5–87 years) was investigated by instrumental neutron activation analysis. Our data reveal that the Co, Rb, Sb, Se, and Zn content increase, while the I/Co content ratio decrease in the normal thyroid of female during a lifespan. Therefore, a goitrogenic and tumorogenic effect of excessive Co, Rb, Sb, Se, and Zn level in the thyroid of old males and of disturbance in intrathyroidal I/Co relationships with increasing age may be assumed. Furthermore, it was found that the levels of Ag, Co, Cr, Fe, Hg, Rb, Sb, Se, and Zn in the thyroid gland are interconnected and depend on the content of I in it. Because I plays a decisive role in the function of the thyroid gland, the data obtained allow us to conclude that, along with I, at least such TEs as Co, Cr, Fe, Rb, Sb, Se, and Zn, if not directly, then indirectly, are involved in the process of thyroid hormone synthesis.

Keywords: Thyroid; Trace Elements; Age-related Changes; Intrathyroidal Trace Elements Relationships; Neutron Activation Analysis

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1. Introduction

According to the World Health Organization (WHO), thyroid diseases rank second among endocrine disorders after diabetes mellitus. More than 665 million people in the world have endemic goiter or suffer from other thyroid pathologies. Women are affected by thyroid diseases almost ten times more often than men. At the same time, according to the same statistics, the increase in the number of thyroid diseases in the world is 5% per year[1]. It has been suggested that risk factors for the development of thyroid disorders may be numerous factors, including genetics, radiation, autoimmune diseases, as well as adverse environmental factors, such as an increase in the content of various chemicals in the environment[2].

Trace elements (TE) are among these various chemicals, because their levels in the environment have increased significantly over the past hundred years as a result of the industrial revolution and the tremendous technological changes that have taken place in metallurgy, chemical production, electronics, agriculture, food processing and storage, cosmetics, pharmaceuticals and medicine. In connection with these changes, the levels and ratio of trace elements entering the human body from the outside have been significantly disturbed, compared with the conditions in which human societies have lived for many millennia.

More than 50 years ago, we formulated the postulate about the somatic TE homeostasis, which is now generally recognized[3]. According to this postulate, under evolutionary environmental conditions, the mechanisms of homeostasis of organisms maintain the levels and ratios of TE in tissues and organs within certain limits. If the content of TE in the environment changes significantly, the mechanisms of somatic homeostasis may respond inadequately. Inadequate response of homeostasis mechanisms leads to changes in TE levels in tissues and organs, which, in turn, can affect their function and lead to the development of pathological conditions. The correctness of this conclusion was illustrated by us earlier on the example of the study of the role of chemical elements such as Hg[4], Co[5], P[6], Sb[7], Cr[8], Ni[9], Al[10], Pb[11], As[12], Ca[13], Sn[14], Ba[15], Be[16], B[17], Bi[18], Cd[19], Sr[20], Tl[21], V[22], and Zn[23,24] in the normal and pathophysiology of the prostate. It was shown, in particular, that a special role in the development of pathological transformations of the prostate is played by disturbances in the relationship between TE in the tissue and gland secretion. Moreover, it was found that changes in the relationship between TE in prostate tissue[25–32] and secret[33–39] can be used as highly informative markers of various prostate diseases, including malignant tumors. These findings stimulated our investigations of TE relationships in thyroid tissue in normal and pathological conditions.

There are many studies regarding TE content in human thyroid, using chemical techniques and instrumental methods[40–52]. However, among the published data, no works on the relationship of TE in the normal human thyroid were found.

This work had three aims. The primary purpose of this study was to determine reliable values for the silver (Ag), cobalt (Co), chromium (Cr), iron (Fe), mercury (Hg), iodine (I), rubidium (Rb), antimony (Sb), scandium (Sc), selenium (Se), and zinc (Zn) mass fractions in the normal thyroid of subjects ranging from children to elderly females using instrumental neutron activation analysis (INAA) and calculate individual values of I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn. The second aim was to compare the Ag, Co, Cr, Fe, Hg, I, Rb, Sb, Sc, Se, and Zn mass fractions in thyroid gland obtained in the study with published data. The final aim was to estimate the inter-correlations of TE contents and I/TE content ratios in normal thyroid of females and changes of these parameters with age.

2. Materials and methods

2.1 Samples

Samples of the human thyroid were obtained from randomly selected autopsy specimens of 33 females (European-Caucasian) aged 3.5 to 87 years. All the deceased were citizens of Obninsk and had undergone routine autopsy at the Forensic Medicine Department of City Hospital, Obninsk. The available clinical data were reviewed for each subject. None of the subjects were receiving medications or used any supplements known to affect thyroid TE contents. The typical causes of sudden death of most of these subjects included trauma or suicide and also acute illness (cardiac insufficiency, stroke, embolism of pulmonary artery, and alcohol poisoning). All right lobes of thyroid glands were divided into two portions using a titanium scalpel[53]. One tissue portion was reviewed by an anatomical pathologist while the other was used for the TE content determination. A histological examination was used to control the age norm conformity as well as the unavailability of microadenomatosis and latent cancer.

All studies were approved by the Ethical Committees of the Medical Radiological Research Centre, Obninsk. All the procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments, or with comparable ethical standards.

2.2 Methods

After the samples intended for TE analysis were weighed, they were transferred to –20 °C and stored until the day of transportation in the Medical Radiological Research Center, Obninsk, where all samples were freeze-dried and homogenized[54]. To determine the contents of the TE by comparison with a known standard, aliquots of commercial, and chemically pure compounds were used[55]. Ten subsamples of the Certified Reference Material (CRM) IAEA H-4 (animal muscle) and IAEA HH-1 (human hair) were analyzed to estimate the precision and accuracy of results. The CRM IAEA H-4 and IAEA HH-1 subsamples were prepared in the same way as the samples of dry homogenized thyroid tissue.

The content of I was determined by INAA using short irradiation in a horizontal channel equipped with the pneumatic rabbit system of the WWR-c research nuclear reactor in Obninsk. The neutron flux in the channel was 1.7×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$. A vertical channel of nuclear reactor WWR-c with a neutron flux of 1.3×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ was applied to determine the content of Ag, Co, Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn by long irradiation. Details of sample preparation and used nuclear reactions, induced radionuclides, gamma-energies and semiconductor spectrometry were presented in our earlier publications concerning TE contents in human scalp hair[56,57].

2.3 Computer program and statistic

A dedicated computer program for INAA mode optimization was used[59]. All thyroid samples were prepared in duplicate, and mean values of TE contents were used in final calculation. Using Microsoft Office Excel, a summary of the statistics, including, arithmetic mean, standard deviation, standard error of mean, minimum and maximum values, median, percentiles with 0.025 and 0.975 levels was calculated for TE contents and I/TE content ratios. Pearson's correlation coefficient was used in Microsoft Office Excel to calculate the relationship "age – TE mass fraction", as well as to identify inter-thyroidal relationships between different TE contents and between different TE content ratios.

3. Results and discussion

3.1 Accuracy of the results

Table 1 depicts comparison of our data for ten TE in ten sub-samples of CRM IAEA H-4 (animal muscle) and IAEA HH-1 (human hair) with the corresponding certified values of TE contents in these materials.

Good agreement of the Ag, Co, Cr, Fe, Hg, I, Rb, Sb, Sc, Se, and Zn contents analyzed by INAA with the certified data of CRMs IAEA H-4 and IAEA HH-1 (**Table 1**) indicates an acceptable accuracy of the results obtained in the study for TE contents and I/TE content ratios in the normal female thyroid presented in **Tables 2–6**.

Table 1. INAA-LLR data of trace element contents in certified reference material IAEA H-4 (animal muscle) and IAEA HH-1 (human hair) compared to certified values ((mg/kg, dry mass basis)

Element	IAEA H-4 animal muscle	This work results	IAEA HH-1 human hair	This work results
	95% confidence interval	M ± SD	95% confidence interval	M ± SD
Ag	–	0.033 ± 0.008	0.19[b]	0.18 ± 0.05
Co	0.0027[b]	0.0034 ± 0.0008	5.97 ± 0.42[a]	5.4 ± 1.1
Cr	0.06[b]	0.071 ± 0.010	0.27[b]	≤0.3
Fe	49.1 ± 6.5[a]	47.0 ± 1.0	23.7 ± 3.1[a]	25.1 ± 4.3
Hg	0.014[b]	0.015 ± 0.004	1.70 ± 0.09[a]	1.54 ± 0.14
I	0.08 ± 0.10[b]	<1.0	20.3 ± 8.9[b]	19.1 ± 6.2
Rb	18.7 ± 3.5[a]	23.7 ± 3.7	0.94[b]	0.89 ± 0.17
Sb	0.0056[b]	0.0061 ± 0.0021	0.031[b]	0.033 ± 0.009
Sc	0.0059[b]	0.0015 ± 0.0009	–	–
Se	0.28 ± 0.08[a]	0.281 ± 0.014	0.35 ± 0.02[a]	0.37 ± 0.08
Zn	86.3 ± 11.5[a]	91 ± 2	174 ± 9[a]	173 ± 17

M – arithmetical mean; SD – standard deviation; a – certified values; b – information values.

3.2 Selection of basic statistical parameters

Table 2 represents certain statistical parameters (arithmetic mean, standard deviation, standard error of mean, minimal and maximal values, median, percentiles with 0.025 and 0.975 levels) of the Ag, Co, Cr, Fe, Hg, I, Rb, Sb, Sc, Se, and Zn mass fractions, as well as I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn mass fraction ratios in normal thyroid of females.

The content of TE was determined in all or most of the examined samples, which made it possible to calculate the main statistical parameters: the mean value of the mass fraction (M), standard deviation (SD), standard error of the mean (SEM), minimum

(Min), maximum (Max), median (Med), and percentiles with levels of 0.025 (P 0.025) and 0.975 (P 0.975), of the Ag, Co, Cr, Fe, Hg, I, Rb, Sb, Sc, Se, and Zn mass fractions, as well as I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn mass fraction ratios in normal thyroid of females (**Table 2**). The values of M, SD, and SEM can be used to compare data for different groups of samples only under the condition of a normal distribution of the results of determining the content of TE in the samples under study. Statistically reliable identification of the law of distribution of results requires large sample sizes, usually several hundred samples, and therefore is rarely used in biomedical research. In the conducted study, we could not prove or disprove the "normality" of the distribution of the results obtained due to the insufficient number of samples studied. Therefore, in addition to the M, SD, and SEM values, such statistical characteristics as Med, range (Min-Max) and percentiles P 0.025 and P 0.975 were calculated, which are valid for any law of distribution of the results of TE content in thyroid tissue.

3.3 The comparison of our results with published data

The comparison of our results with published data for the Ag, Co, Cr, Fe, Hg, I, Rb, Sb, Sc, Se, and Zn contents in the human thyroid is shown in **Table 3**.

Table 2. Some statistical parameters of Ag, Co, Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn mass fraction (mg/kg, dry mass basis) as well as I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn mass fraction ratios in normal female thyroid (n = 33)

	M	SD	SEM	Min	Max	Median	P 0.025	P 0.975
Ag	0.0140	0.0093	0.0020	0.0012	0.0331	0.0130	0.0021	0.0321
Co	0.0505	0.0322	0.0064	0.0170	0.140	0.0405	0.0183	0.130
Cr	0.573	0.246	0.049	0.290	1.22	0.488	0.303	1.11
Fe	232	112	22	63.0	512	199	64.8	480
Hg	0.0329	0.0246	0.0051	0.0065	0.100	0.0263	0.0079	0.100
I	1,751	1,169	224	110	5,345	1,504	296	4,201
Rb	6.16	2.42	0.48	1.11	12.8	6.30	2.38	10.8
Sb	0.116	0.063	0.012	0.0115	0.248	0.108	0.0183	0.247
Sc	0.0042	0.0040	0.0012	0.0002	0.0143	0.0032	0.0003	0.0124
Se	2.22	1.19	0.23	0.439	5.32	2.07	0.773	4.85
Zn	85.7	38.0	7.44	8.10	166	83.0	22.9	156
I/Ag	219,340	214,640	47,995	34,688	995,833	159,139	51,691	755,562
I/Co	48,541	31,998	6,672	5,182	137,235	41,503	6,506	119,377
I/Cr	3,934	2,109	440	140	7,700	3,758	699	7,599
I/Fe	11.2	10.2	2.1	1.81	47.0	8.53	2.21	35.8
I/Hg	90,366	70,915	15,475	3,642	239,858	68,186	6,371	229,852
I/Rb	357	237	48	73.5	811	266	88.7	807
I/Sb	18,494	10,641	2,172	5,328	41,121	14,445	7,010	39,838
I/Sc	2,444,968	4,120,554	1,242,394	65,804	13,150,000	569,048	81,953	11,670,000
I/Se	1,083	958	196	180	4,361	925	226	3,624
I/Zn	28.8	27.6	5.6	5.66	133	22.7	6.28	104

M – arithmetic mean; SD – standard deviation; SEM – standard error of mean; Min – minimum value; Max – maximum value; P 0.025 – percentile with 0.025 level; P 0.975 – percentile with 0.975 level.

Values obtained for Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn contents in the normal human thyroid (**Table 3**) agree well with median of mean values reported by other researches[40–52]. The obtained means for Ag and Co were almost one order of magnitude lower median of previously reported means but inside the range of means (**Table 3**). Data cited in **Table 3** also includes samples obtained from patients who died from different non-endocrine diseases. A number of values for TE mass fractions were not expressed on a dry mass basis by the authors of the cited references. However, we calculated these values using published data for water (75%)[42] and ash (4.16% on dry mass basis)[59] contents in thyroid of adults. No published data referring to I/Ag, I/Co, I/Cr, I/Fe, I/Hg, I/Rb, I/Sb, I/Sc, I/Se, and I/Zn mass fraction ratios in human thyroid was found.

3.4 The effect of age on the TE contents

To estimate the effect of age on the TE contents and I/TE content ratios in normal thyroid of females Pearson's correlation coefficient was used (**Table 4**). With age, the Co, Rb, Sb, Se, and Zn content increase, while the I/Co content ratio decrease (**Table 4**).

These characteristics can be used to estimate the "biological age" of the female thyroid gland.

Table 3. Median, minimum and maximum value of means Ag, Co, Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn contents in normal human thyroid according to data from the literature in comparison with our results (mg/kg, dry mass basis)

Element	Published data [Reference]			This work
	Median of means (n)*	Minimum of means M or M ± SD, (n)**	Maximum of means M or M ± SD, (n)**	Males and females M ± SD
Ag	0.25 (12)	0.000784 (16)[40]	1.20 ± 1.24 (105)[41]	0.0140 ± 0.0093
Co	0.336 (17)	0.026 ± 0.031 (46)[42]	70.4 ± 40.8 (14)[43]	0.0505 ± 0.0322
Cr	0.69 (17)	0.105 (18)[44]	24.8 ± 2.4 (4)[45]	0.573 ± 0.246
Fe	252 (21)	56 (120)[46]	2,444 ± 700 (14)[43]	232 ± 112
Hg	0.08 (13)	0.0008 ± 0.0002 (10)[47]	396 ± 40 (4)[45]	0.0329 ± 0.0246
I	1,888 (95)	159 ± 8 (23)[48]	5,772 ± 2,708 (50)[49]	1,751 ± 1,169
Rb	12.3 (9)	≤0.85 (29)[47]	294 ± 191 (14)[43]	6.16 ± 2.42
Sb	0.105 (10)	0.040 ± 0.003 (–)[50]	4.0 (–)[51]	0.116 ± 0.063
Sc	0.009 (4)	0.0018 ± 0.0003 (17)[52]	0.0135 ± 0.0045 (10)[47]	0.0042 ± 0.0040
Se	2.61 (17)	0.95 ± 0.08 (29)[47]	756 ± 680 (14)[43]	2.22 ± 1.19
Zn	118 (51)	32 (120)[46]	820 ± 204 (14)[43]	85.7 ± 38.0

M – arithmetic mean; SD – standard deviation; (n)* – number of all references; (n)** – number of samples.

Table 4. Correlations between age (years) and trace element content (mg/kg, dry tissue), as well as between age and I/trace element mass fraction ratios in the normal female thyroid (*r* – coefficient of correlation)

El	Ag	Co	Cr	Fe	Hg	I	Rb	Sb	Sc	Se	Zn
r	0.27	0.59[b]	0.20	0.24	–0.06	0.19	0.50[b]	0.53[b]	0.47[a]	0.61[c]	0.62[c]
Ratio	I/Ag	I/Co	I/Cr	I/Fe	I/Hg	I/Rb	I/Sb	I/Sc	I/Se	I/Zn	–
r	–0.12	–0.33[a]	0.01	0.21	0.23	–0.14	–0.25	0.07	–0.20	–0.29	–

El – element; Statistically significant values: [a] $p \leq 0.05$, [b] $p \leq 0.01$, [c] $p \leq 0.001$.

3.5 The inter-thyroidal correlation of TE and I/TE ratios

The data of inter-thyroidal correlation (values of *r* – Pearson's coefficient of correlation) including all TE and I/TE content ratios identified by us are presented in **Tables 5** and **6**, respectively.

Table 5. Intercorrelations of the trace element mass fractions in normal female thyroid (*r* – coefficient of correlation)

El	Co	Cr	Fe	Hg	I	Rb	Sb	Sc	Se	Zn
Ag	0.18	–0.08	–0.47[a]	–0.34	0.69[b]	–0.23	0.41[a]	–0.16	0.25	0.01
Co	**1.00**	0.50[a]	–0.04	–0.26	0.49[a]	0.57[b]	0.64[c]	0.41[a]	0.61[b]	0.80[c]
Cr	0.50[a]	**1.00**	–0.17	–0.24	0.38[a]	0.26	0.32	–0.13	0.21	0.31
Fe	–0.04	–0.17	**1.00**	0.55[b]	–0.13	0.11	–0.07	–0.10	–0.24	0.21
Hg	–0.26	–0.24	0.55[b]	**1.00**	–0.14	–0.05	–0.35[a]	–0.08	–0.15	–0.17
I	0.49[a]	0.38[a]	–0.13	–0.14	**1.00**	0.13	0.68[c]	–0.38	0.39[a]	0.58[b]
Rb	0.57[b]	0.26	0.11	–0.05	0.13	**1.00**	0.28	0.42[a]	0.40[a]	0.58[b]
Sb	0.64[c]	0.32	–0.07	–0.35[a]	0.68[c]	0.28	**1.00**	–0.21	0.67[c]	0.44[a]
Sc	0.41[a]	–0.13	–0.10	–0.08	–0.38	0.42[a]	–0.21	**1.00**	0.31	0.52[a]
Se	0.61[b]	0.21	–0.24	–0.15	0.39[a]	0.40[a]	0.67[c]	0.31	**1.00**	0.47[a]
Zn	0.80[c]	0.31	0.21	–0.17	0.22	0.58[b]	0.44[a]	0.52[a]	0.47[a]	**1.00**

El – element; Significant values: [a] $p \leq 0.05$, [b] $p \leq 0.01$, [c] $p \leq 0.001$.

Table 6. Intercorrelations of the I/trace element mass fraction ratios in normal female thyroid (*r* – coefficient of correlation)

Ratio	I/Co	I/Cr	I/Fe	I/Hg	I/Rb	I/Sb	I/Sc	I/Se	I/Zn
I/Ag	–0.01	–0.14	–0.23	–0.28	–0.06	–0.09	–0.14	–0.05	–0.01
I/Co	**1.00**	0.68[c]	0.42[a]	0.41[a]	0.72[c]	0.54[b]	0.08	0.65[c]	0.74[c]
I/Cr	0.68[c]	**1.00**	0.62[b]	0.53[b]	0.90[c]	0.56[b]	0.61[a]	0.64[c]	0.64[c]
I/Fe	0.42[a]	0.62[b]	**1.00**	0.72[c]	0.74[c]	0.22	0.54	0.37	0.53[b]
I/Hg	0.41[a]	0.53[b]	0.72[c]	**1.00**	0.61[b]	0.13	0.59	0.53[a]	0.47[a]
I/Rb	0.72[c]	0.90[c]	0.74[c]	0.61[b]	**1.00**	0.61[b]	0.60[a]	0.66[c]	0.71[c]
I/Sb	0.54[b]	0.56[b]	0.22	0.13	0.61[b]	**1.00**	0.23	0.65[c]	0.55[b]
I/Sc	0.54[b]	0.61[a]	0.54	0.59	0.60[a]	0.23	**1.00**	0.50	0.48
I/Se	0.65[c]	0.64[c]	0.37	0.53[a]	0.66[c]	0.65[c]	0.50	**1.00**	0.80[c]
I/Zn	0.74[c]	0.64[c]	0.53[b]	0.47[a]	0.71[c]	0.55[b]	0.48	0.80[c]	**1.00**

Significant values: [a] $p \leq 0.05$, [b] $p \leq 0.01$, [c] $p \leq 0.001$.

A significant direct correlation between the I and Ag, Co, Cr, Sb, Se mass fractions was seen in female thyroid (**Table 5**). Since no correlations were found between I and other TE, for example Fe, Rb, and Zn, it would appear that the content of these TE in the thyroid gland is independent of its content of I. However, this is not quite so. If we bring the content of the studied TE to the content of I (I/TE content ratio), then there are close strong relationships between I/Fe, I/Rb, and I/Zn and all other I/TE content ratios with I/Ag and I/Sc only exception (**Table 6**). From this it follows that, at least, the levels of Co, Cr, Fe, Rb, Sb, Se, and Zn in the thyroid gland are interconnected and depend on the content of I in it. Because I plays a decisive role in the function of the thyroid gland, the data obtained allow us to conclude that, along with I, such TEs as Co, Cr, Fe, Rb, Sb, Se, and Zn, if not directly, then indirectly, are involved in the process of thyroid hormone synthesis.

4. Conclusion

The neutron activation analysis is a useful analytical tool for the non-destructive determination of TE contents in the thyroid tissue samples. This method allows at least determine means for Ag, Co, Cr, Fe, Hg, Rb, Sb, Sc, Se, and Zn (ten TE).

Our data reveal that the Co, Rb, Sb, Se, and Zn content increase, while the I/Co content ratio decrease in the normal thyroid of female during a lifespan. Therefore, a goitrogenic and tumorogenic effect of excessive Co, Rb, Sb, Se, and Zn level in the thyroid of old males and of disturbance in intrathyroidal I/Co relationships with increasing age may be assumed. Furthermore, it was found that the levels of Ag, Co, Cr, Fe, Hg, Rb, Sb, Se, and Zn in the thyroid gland are interconnected and depend on the content of I in it. Because I plays a decisive role in the function of the thyroid gland, the data obtained allow us to conclude that, along with I, at least such TEs as Co, Cr, Fe, Rb, Sb, Se, and Zn, if not directly, then indirectly, are involved in the process of thyroid hormone synthesis. Thus, the results obtained show that not only I and Se, but also many other TE can effect on the synthesis of thyroid hormones. Further studies should be aimed at a detailed investigation of the role of Co, Cr, Fe, Rb, Sb, Zn and other TE in the synthesis of thyroid hormones.

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Conflict of interest

The author declares that he has no conflict of interest.

References

1. Wang H, Jiang Y, Song J, *et al*. The risk of perchlorate and iodine on the incidence of thyroid tumors and nodular goiter: A case-control study in southeastern China. Environmental Health 2022; 21: 4. doi: 10.1186/s12940-021-00818-8.
2. Tang Z, Zhang J, Zhou Q, *et al*. Thyroid Cancer "epidemic": A socio-environmental health problem needs collaborative efforts. Environmental Science & Technology 2020; 54(7): 3725–3727. doi: 10.1021/acs.est.0c00852.
3. Zaichick V. Medical elementology as a new scientific discipline. Journal of Radioanalytical and Nuclear Chemistry 2006; 269: 303–309. doi: 10.1007/s10967-006-0383-3.
4. Zaichick V. A systematic review of the mercury content of the normal human prostate gland. Archives of Urology 2020; 3(2): 35–45. doi: 10.22259/2638-5228.0302005.
5. Zaichick V. A systematic review of the cobalt content of the normal human prostate gland. Journal of Clinical Research in Oncology 2020; 3(1): 1–8. doi: 10.33309/2639-8230.030102.
6. Zaichick V. A systematic review of the phosphorus content of the normal human prostate gland. Applied Medical Research 2020; 7(2): 1–7. doi: 10.47363/AMR/2020(7)183.
7. Zaichick V. A systematic review of the antimony content of the normal human prostate gland. Journal of Hematology and Oncology Research 2021; 4(1): 17–27. doi: 10.14302/issn.2372-6601.jhor-20-3673.
8. Zaichick V. A systematic review of the chromium content of the normal human prostate gland. Innovare Journal of Medical Sciences 2021; 9(1): 1–6. doi: 10.22159/ijms.2021.v9i1.40375.
9. Zaichick V. A systematic review of the nickel content of the normal human prostate gland. Health Sciences 2020; 1: 1–6. doi: 10.15342/hs.2020.334.
10. Zaichick V. A systematic review of the aluminum content of the normal human prostate gland. Advances in Hematology and Oncology Research 2021; 4(1): 59–65. doi: 10.33140/AHOR.04.01.01.
11. Zaichick V. A systematic review of the lead content of the normal human prostate gland. Journal of Cancer and Oncology Research 2021; 2(1): 1–8.
12. Zaichick V. A systematic review of the arsenic

content of the normal human prostate gland. International Journal of Medicine Sciences 2021; 3(1): 1–6.
13. Zaichick V. A systematic review of the calcium content of the normal human prostate gland. Iberoamerican Journal of Medicine 2021; 3(1): 85–94. doi: 10.5281/zenodo.4429712.
14. Zaichick V. A systematic review of the tin content of the normal human prostate gland. Journal of Cellular & Molecular Oncology 2021; 3(1): 1–7.
15. Zaichick V. Barium levels in the prostate of the normal human: A review. Universal Journal of Pharmaceutical Research 2021; 6(1): 52–60. doi: 10.22270/ujpr.v6i1.541.
16. Zaichick V. Beryllium content of the normal human prostate gland: A systematic review. Acta Scientific Medical Sciences 2021; 5(4): 78–85. doi: 10.31080/ASMS.2020.05.0872.
17. Zaichick V. Boron level in the prostate of the normal human: A systematic review. Journal of Nanotechnology and Nano Science Research 2021; 1(2): 1–9.
18. Zaichick V. Bismuth level in the prostate of normal human: A systematic review. International Journal of Bioprocess & Biotechnological Advancements 2021; 7(1): 264–273.
19. Zaichick V, Wynchank S. A systematic review of the cadmium content of the normal human prostate gland. World Journal of Advanced Research and Reviews 2021; 10(1): 258–269. doi: 10.30574/wjarr.2021.10.1.0162.
20. Zaichick V. A systematic review of the strontium content of the normal human prostate gland. Journal of Medical Research and Health Sciences 2021; 4 (5): 1257–1269. doi: 10.15520/jmrhs.v4i5.349.
21. Zaichick V. Thallium content of the normal human prostate gland—A systematic review. Archives of Clinical Case Reports 2021; 2(5): 223–229.
22. Zaichick V. Vanadium content of the normal human prostate gland: A systematic review. Archives of Pharmacy Practice 2021; 12(3): 15–21. doi: 10.51847/GTsA5lvcGW.
23. Zaichick V. A systematic review of the zinc content of the normal human prostate gland. Biological Trace Element Research 2021; 199(10): 3593–3607. doi: 10.1007/s12011-020-02495-z.
24. Zaichick V. A systematic review of the zinc content of the hyperplastic human prostate gland. Biomedical Research on Trace Elements 2020; 31(3): 98–116. doi: 10.11299/brte.31.98.
25. Zaichick V, Zaichick S. Ratios of selected chemical element contents in prostatic tissue as markers of malignancy. Hematology and Medical Oncology 2016; 1(2): 1–8. doi: 10.15761/HMO.1000109.
26. Zaichick V, Zaichick S. Ratios of Zn/trace element contents in prostate gland as carcinoma's markers. Cancer Reports and Reviews 2017; 1(1): 1–7. doi: 10.15761/CRR.1000105.
27. Zaichick V, Zaichick S. Ratios of magnesium/trace element contents in prostate gland as carcinoma's markers. SAJ Cancer Science 2017; 2(1): 102.
28. Zaichick V, Zaichick S. Ratios of calcium/trace elements as prostate cancer markers. Journal of Oncology Research and Therapy 2017; 2017(4): J116. doi: 10.29011/2574-710X.000016.
29. Zaichick V, Zaichick S. Ratios of cobalt/trace element contents in prostate gland as carcinoma's markers. International Journal of Cancer Epidemiology and Research 2017; 1(1): 21–27.
30. Zaichick V, Zaichick S. Ratios of cadmium/trace element contents in prostate gland as carcinoma's markers. Cancer Therapy and Oncology International Journal 2017; 4(1): 555626. doi: 10.19080/CTOIJ.2017.04.555626.
31. Zaichick V, Zaichick S. Ratios of selenium/trace element contents in prostate gland as carcinoma's markers. Journal of Tumor Medicine & Prevention 2017; 1(2): 555556. doi: 10.19080/JTMP.2017.01.555556.
32. Zaichick V, Zaichick S. Ratios of rubidium/trace element contents in prostate gland as carcinoma's markers. Cancer Research and Clinical Oncology 2017; 1(1): 13–21.
33. Zaichick V, Zaichick S. Ratio of zinc to bromine, iron, rubidium, and strontium concentration in the prostatic fluid of patients with benign prostatic hyperplasia. Acta Scientific Medical Sciences 2019; 3(6): 49–56.
34. Zaichick V, Zaichick S. Ratio of zinc to bromine, iron, rubidium, and strontium concentration in expressed prostatic secretions as a source for biomarkers of prostatic cancer. American Journal of Research 2019; 5-6: 140–150. doi: 10.26739/2573-5616-2019-6-15.
35. Zaichick V, Zaichick S. Some trace element contents and ratios in prostatic fluids as ancillary diagnostic tools in distinguishing between the benign prostatic hyperplasia and chronic prostatitis. Archives of Urology 2019; 2(1): 12–20. doi: 10.22259/2638-5228.0201004.
36. Zaichick V, Zaichick S. Some trace element contents and ratios in prostatic fluids as ancillary diagnostic tools in distinguishing between the chronic prostatitis and prostate cancer. Medical Research and Clinical Case Reports 2019; 3(1): 1–10.
37. Zaichick V, Zaichick S. Using prostatic fluid levels of zinc to strontium concentration ratio in non-invasive and highly accurate screening for prostate cancer. Acta Scientific Cancer Biology 2020; 4(1): 12–21.
38. Zaichick V, Zaichick S. Using prostatic fluid levels of zinc to iron concentration ratio in non-invasive and highly accurate screening for prostate cancer. SSRG International Journal of Medical Science 2019; 6(11): 24–31. doi: 10.14445/23939117/IJMS-V6I11P108.
39. Zaichick V. Using prostatic fluid levels of rubidium and zinc concentration multiplication in non-invasive and highly accurate screening for prostate

cancer. Journal of Cancer Prevention & Current Research 2019; 10(6): 151–158. doi: 10.15406/jcpcr.2019.10.00409.
40. Zhu H, Wang N, Zhang Y, *et al*. Element contents in organs and tissues of Chinese adult men. Health Physics 2010; 98(1): 61–73. doi: 10.1097/HP.0b013e3181bad921.
41. Vlasova ZA. Dynamics of trace element contents in thyroid gland in connection with age and atherosclerosis. Proceedings of the Leningrad Institute of Doctor Advanced Training 1969; 80: 135–144.
42. Katoh Y, Sato T, Yamamoto Y. Determination of multielement concentrations in normal human organs from the Japanese. Biological Trace Element Research 2002; 90(1-3): 57–70. doi: 10.1385/BTER:90:1-3:57.
43. Salimi J, Moosavi K, Vatankhah S, Yaghoobi A. Investigation of heavy trace elements in neoplastic and non-neoplastic human thyroid tissue: A study by proton-induced X-ray emissions. International Journal of Radiation Research 2004; 1(4): 211–216.
44. Tipton IH, Cook MJ. Trace elements in human tissue. II. Adult subjects from the United States. Health Physics 1963; 9(2): 103–145. doi: 10.1097/00004032-196302000-00002.
45. Reddy SB, Charles MJ, Kumar MR, *et al*. Trace elemental analysis of adenoma and carcinoma thyroid by PIXE method. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 2002; 196(3-4): 333–339. doi: 10.1016/S0168-583X(02)01292-2.
46. Ataulchanov IA. Age changes in the content of manganese, cobalt, copper, zinc and iron in the endocrine glands of women. Problemy Endokrinologii 1969; 15(2): 98–102.
47. Boulyga SF, Zhuk IV, Lomonosova EM, *et al*. Determination of microelements in thyroids of the inhabitants of Belarus by neutron activation analysis using the k_0-method. Journal of Radioanalytical and Nuclear Chemistry 1997; 222(1-2): 11–14. doi: 10.1007/BF02034238.
48. Neimark II, Timoschnikov VM. Development of thyroid cancer in persons living in the endemic goiter area. Problemy Endokrinilogii 1978; 24(3): 28–32.
49. Zabala J, Carrion N, Murillo M, *et al*. Determination of normal human intrathyroidal iodine in Caracas population. Journal of Trace Elements in Medicine and Biology 2009; 23(1): 9–14. doi: 10.1016/j.jtemb.2008.11.002.
50. Boulyga SF, Becker JS, Malenchenko AF, Dietze HJ. Application of ICP-MS for multielement analysis in small sample amounts of pathological thyroid tissue. Microchimica Acta 2000; 134(3-4): 215–222. doi: 10.1007/s006040050069.
51. Fuzailov YuM. Reaction of human and animal thyroids in the conditions of antimony sub-region of the Fergana valley. In: Kovalsky VV (editor). IX All-Union Conference on Trace Elements in Biology; Kishinev. 1981. p. 58–62.
52. Kvicala J, Havelka J, Zeman J, Němec J. Determination of some trace elements in the thyroid gland by INAA. Journal of Radioanalytical and Nuclear Chemistry 1991; 149(2): 267–274. doi: 10.1007/BF02062052.
53. Zaichick V, Zaichick S. Instrumental effect on the contamination of biomedical samples in the course of sampling. The Journal of Analytical Chemistry 1996; 51(12): 1200–1205.
54. Zaichick V, Zaichick S. A search for losses of chemical elements during freeze-drying of biological materials. Journal of Radioanalytical and Nuclear Chemistry 1997; 218(2): 249–253. doi: 10.1007/BF02039345.
55. Zaichick V. Applications of synthetic reference materials in the medical radiological research centre. Fresenius' Journal of Analytical Chemistry 1995; 352: 219–223. doi: 10.1007/BF00322330.
56. Zaichick S, Zaichick V. The effect of age and gender on 37 chemical element contents in scalp hair of healthy humans. Biological Trace Element Research 2010; 134(1): 41–54. doi: 10.1007/s12011-009-8456-0.
57. Zaichick S, Zaichick V. The scalp hair as a monitor for trace elements in biomonitoring of atmospheric pollution. International Journal of Environment and Health 2011; 5(1/2): 106–124. doi: 10.1504/IJENVH.2011.039860.
58. Korelo AM, Zaichick V. Software to optimize the multielement INAA of medical and environmental samples. In: Nazarov VM (editor). Activation analysis in environment protection. Dubna, Russia: Joint Institute for Nuclear Research; 1993. p. 326–332.
59. Schroeder HA, Tipton IH, Nason AP. Trace metals in man: Strontium and barium. Journal of Chronic Diseases 1972; 25(9): 491–517. doi: 10.1016/0021-9681(72)90150-6.