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Comparative Hair Trace Element Profile in the Population of Sakhalin and Taiwan Pacific Islands

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Abstract The objective of the current study is to perform a comparative analysis of hair trace element content in 393 apparently healthy adults living in Taipei, Taiwan, Republic of China (94 women and 46 men) and Yuzhno-Sakhalinsk, Sakhalin, Russia (186 women and 67 men). The obtained data indicate that Yuzhno-Sakhalinsk inhabitants were characterized by significantly higher hair Co, Cr, Mn, and V levels, exceeding the respective Taipei values by a factor of 3, 2, 7, and 5, respectively (all $p < 0.001$). Hair Cu, Fe, and Si levels were also higher in examinees from Yuzhno-Sakhalinsk than those from Taipei by 10% ($p = 0.001$), 61% ($p < 0.001$), and 68% ($p < 0.001$), respectively. It is notable that the only essential element, being significantly higher (+ 30%; $p < 0.001$) in Taipei inhabitants, is selenium. Yuzhno-Sakhalinsk inhabitants were characterized by 60% higher levels of hair Sn, and nearly two- and threefold higher scalp hair content of Be and Cd in comparison to Taipei values, respectively (all $p < 0.001$). Oppositely, the examinees from Taipei had 14% ($p = 0.040$) and 47% ($p = 0.001$) higher levels of hair As and Hg as compared to Yuzhno-Sakhalinsk inhabitants. Further analysis demonstrated that men from both Yuzhno-Sakhalinsk and Taipei were characterized by significantly higher hair Mn, As, and Pb levels in comparison to women. The intensive development of heavy industry in Yuzhno-Sakhalinsk may result in increased metal emissions, whereas fish consumption may result in elevation of hair Hg, As, and Se levels in Taiwan inhabitants.

Keywords Hair · Trace elements · Selenium · Mercury · Biomonitoring

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Introduction

Increased risk of heavy metal pollution may result in adverse health effects [1]. At the same time, even essential metals that are required for normal organism's functioning may be toxic in the case of overexposure [2]. Hair multi-bioelement profile biomonitoring is an effective tool for assessment of metal exposure, as it reflects not only the exposing dose of certain chemical but also its bioavailability using a variety of species [3]. Human biomonitoring has been supposed as one of the most perspective in this regard [4]. Different matrices of the human body were used for assessment of chemical exposure. Blood is one of the most informative samples [5]. However, its use is limited by invasiveness and high storage requirements. Therefore, the search for non-invasive and informative matrices for human biomonitoring is of great importance [6]. Using human hair has a number of

advantages like high mineralization, the ease of sampling and storage. Moreover, in contrast to blood and urine, hair may indicate the "history" of metal exposure as incorporation of elements into hair matrix is irreversible and does not undergo homeostatic regulation [7]. Therefore, the use of human hair may be effective in biomonitoring of metal exposure. In particular, it has been shown that hair mineral content may reflect metal exposure from occupational [8], dietary [9], and geological [10] sources.

Numerous studies have investigated hair element content in persons living in continental Russia [11, 12] and China [13, 14]. At the same time, the existing data on hair trace element content in persons living in Taiwan and Sakhalin are rather limited. These islands are located in the Pacific Ocean both being eastern offshore islands of continental China and Russia and consequently share certain similar geochemical features.

Therefore, the primary aim of the current study is comparative analysis of hair trace element content in men and women adults living in Taipei (Taiwan, Republic of China) and Yuzhno-Sakhalinsk (Sakhalin, Russia).

Subjects and Methods

The present investigation involved a total of 393 apparently healthy adult volunteers living in Taipei, Taiwan, Republic of China (94 women, 51 ± 6 years old, and 46 men, 51 ± 7 years old) and Yuzhno-Sakhalinsk, Sakhalin, Russia (186 women, 51 ± 6 years old and 67 men, 51 ± 5 years old). The protocol of the study was approved by the Local Ethics Committee, and procedures were performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All examinees gave their informed consent prior to the inclusion in the study. The studied cohorts were formed using the following exclusion criteria: occupational exposure to metals; smoking (current and former smokers); acute infectious, surgical and traumatic diseases; endocrine disorders; metallic implants; pregnancy and lactation; vegetarian diet; and alcoholism.

Proximal parts of occipital scalp hair strands were collected using pre-cleaned stainless steel scissors in a quantity of 0.1 g. All examinees have washed hair at the day of sampling with their usual shampoos. Despite different mineral composition of the commercially available shampoos earlier study has indicated that their use does not alter hair trace element content significantly [15]. In order to decrease the influence of external contamination on the results of hair analysis, the obtained samples were washed with acetone and rinsed thrice with deionized water [16] with subsequent air drying.

Further pre-analytic preparation included microwave digestion of the hair samples. In particular, hair samples were introduced into Teflon containers and added with concentrated HNO_3. Microwave digestion was performed in a Berghof speedwave four system (Berghof Products and Instruments, Germany) at 170–180 °C for 20 min. The obtained samples were added with deionized water to a final volume of 15 ml.

The obtained solution was analyzed for trace element content using inductively coupled plasma mass spectrometry (ICP-MS) at NexION 300D (PerkinElmer Inc., Shelton, CT 06484, USA) using "Dynamic Reaction Cell technology" (DRC) removing the majority of interferences with little or no loss of analyte sensitivity and equipped with ESI SC-2 DX4 autosampler (Elemental Scientific Inc., Omaha, NE 68122, USA). The system was prepared in accordance with the manufacturer's specifications (Table 1) and calibrated using multi-element standards. In particular, solutions containing chemical elements in concentrations of 0.5, 5, 10, and 50 μg/l were prepared from Universal Data Acquisition Standards Kit (PerkinElmer Inc., Shelton, CT 06484, USA).

The certified reference material of human hair GBW09101 (Shanghai Institute of Nuclear Research, Academia Sinica, China) was used for laboratory quality control (Table 2). Chemical analysis was performed in an accredited clinic-diagnostic laboratory of autonomous non-profit organization "Centre for Biotic Medicine" (ISO 9001:2000; certificate 4017 from 05.04.2006, "BM TRADA" Certification Limited Incorporating CQA (UK)), an IUPAC company associate.

The obtained data were processed using R language ver. 3.4.0 (2017-04-21) using *reshape2 1.4.2*, *dplyr* 0.7.0 and built-in packaged for subsetting and statistics; *ggplot2* 2.2.1 and *cairo* 1.5–9 for plots. Data normality was assessed using Shapiro-Wilk test. Descriptive statistics of hair element content included the estimation of median and the respective 25 and 75 percentile boundaries. Mann-Whitney *U* test was used for group comparison. False discovery rate (FDR) adjustment for *p* value was applied due to multiple comparisons. The difference between the group values was considered significant at $p < 0.05$.

Results

General Comparison of Taipei and Yuzhno-Sakhalinsk Cohorts

Group comparisons of the total cohorts from Taipei and Yuzhno-Sakhalinsk demonstrated significant difference in hair essential (Fig. 1) and toxic (Fig. 2) trace element content. In particular, Yuzhno-Sakhalinsk inhabitants were characterized by three- ($p < 0.001$), two- ($p < 0.001$), seven- ($p < 0.001$), and fivefold ($p < 0.001$) higher hair Co, Cr, Mn, and V levels in comparison to the respective Taipei values. Hair Cu, Fe, and Si levels were also higher in Yuzhno-Sakhalinsk examinees than those in Taipei by 10% ($p = 0.001$), 61% ($p < 0.001$), and 68% ($p < 0.001$), respectively. It is notable that the only essential element, being significantly higher (+ 30%; $p < 0.001$) in Taipei inhabitants, is selenium. Less significant difference was observed in hair toxic trace elements. In particular, Yuzhno-Sakhalinsk inhabitants

Table 1 System characteristics and settings for trace element analysis

Plasma power, W	1500
Plasma argon flow, L/min	18
Aux argon flow, L/min	1.6
Nebulizer argon flow, L/min	0.98
Sample introduction system	ESI ST PFA concentric nebulizer and ESI PFA cyclonic spray chamber (Elemental Scientific Inc., Omaha, NE 68122, USA)
Sampler and skimmer cone material	Platinum
Injector	ESI Quartz 2.0 mm I.D.
Sample flow, μL/min	637
Internal standard flow, μL/min	84
Dwell time and acquisition mode	10–100 ms and peak hopping for all analytes
Sweeps per reading	1
Reading per replicate	10
Replicate number	3

were characterized by 60% higher levels of hair Sn ($p < 0.001$), and nearly two- ($p < 0.001$) and threefold higher ($p < 0.001$) scalp hair content of Be and Cd in comparison to Taipei values, respectively. Oppositely, the examinees from Taipei had 14% ($p = 0.040$) and 47% ($p = 0.001$) higher levels of hair As and Hg as compared to Yuzhno-Sakhalinsk inhabitants.

Assessment of Gender Differences within Taipei and Yuzhno-Sakhalinsk Cohorts

Further analysis (Table 2) indicates that men from Taipei are characterized by 71% ($p < 0.001$) higher values of hair Mn as compared to women. Hair Mn content in Yuzhno-Sakhalinsk inhabitants was more than twofold lower in male examinees ($p < 0.001$). Gender differences were more expressed in Yuzhno-Sakhalinsk. In particular, men living in Yuzhno-Sakhalinsk are characterized by 55% lower hair Co levels as compared to women ($p = 0.009$). In turn, the scalp hair content of Cr, Se, and V in males exceeded the respective female values by 29% ($p = 0.001$), 41% ($p = 0.018$), and 36% ($p = 0.001$).

Toxic trace elements were also affected by gender and geography (Tables 3 and 4). Men living in Taipei and Yuzhno-Sakhalinsk are characterized by nearly twofold ($p < 0.001$) and threefold ($p < 0.001$) higher values of hair As in comparison to women, respectively. Similarly, hair Pb levels in men from Taipei and Yuzhno-Sakhalinsk were threefold higher than in females ($p < 0.001$ for both comparisons). Toxic trace element levels were also more variable in Yuzhno-Sakhalinsk inhabitants. In particular, hair Al, Cd, and Hg levels in men living in Yuzhno-Sakhalinsk significantly exceeded the respective female values by 46% ($p = 0.001$), 93% ($p < 0.001$), and 25% ($p = 0.027$).

Table 2 Comparison of the certified and the estimated values of chemical element concentration in the reference material of human hair GBW09101

Element	Certified value, μg/g	Lower limit, μg/g	Upper limit, μg/g	Obtained value, μg/g	Recovery, %	BEC, μg/l	LOD, μg/l
Al	23.2	21.2	25.2	23.2 ± 2.22	100	0.270	0.130
As	0.198	0.175	0.221	0.194 ± 0.014	98	0.001	0.001
Be	n.d.	n.d.	n.d.	0.0015 ± 0.0571	n.d.	0.0004	0.0008
Cd	0.072	0.062	0.082	0.057 ± 0.006	78	0.0006	0.0016
Co	0.153	0.138	0.168	0.126 ± 0.026	82	0.0021	0.0013
Cr	8.74	7.77	9.71	7.87 ± 1.49	90	0.023	0.023
Cu	33.6	31.3	35.9	35.8 ± 8.4	106	0.024	0.004
Fe	160	144	176	147 ± 18	91	0.113	0.080
Hg	1.06	0.78	1.34	1.35 ± 0.29	127	0.034	0.012
I	0.96	0.76	1.16	1.21 ± 0.92	126	0.091	0.008
Li	n.d.	n.d.	n.d.	0.042 ± 0.007	n.d.	0.019	0.003
Mn	3.83	3.44	4.22	3.11 ± 0.28	81	0.027	0.010
Ni	5.77	5.77	5.77	4.35 ± 1.3	75	0.026	0.009
Pb	3.83	3.65	4.01	4.23 ± 0.58	110	0.001	0.001
Se	0.59	0.55	0.63	0.59 ± 0.08	100	0.027	0.013
Si	n.d.	n.d.	n.d.	33.52 ± 22.7	n.d.	9.180	0.320
Sn	n.d.	n.d.	n.d.	0.997 ± 0.935	n.d.	0.002	0.001
V	0.089	0.089	0.089	0.079 ± 0.012	89	0.0002	0.0003
Zn	191	175	207	197 ± 19	103	0.221	0.070

Content is presented as mean ± standard deviation

n.d. not defined, *BEC* background equivalent concentration, *LOD* limit of detection

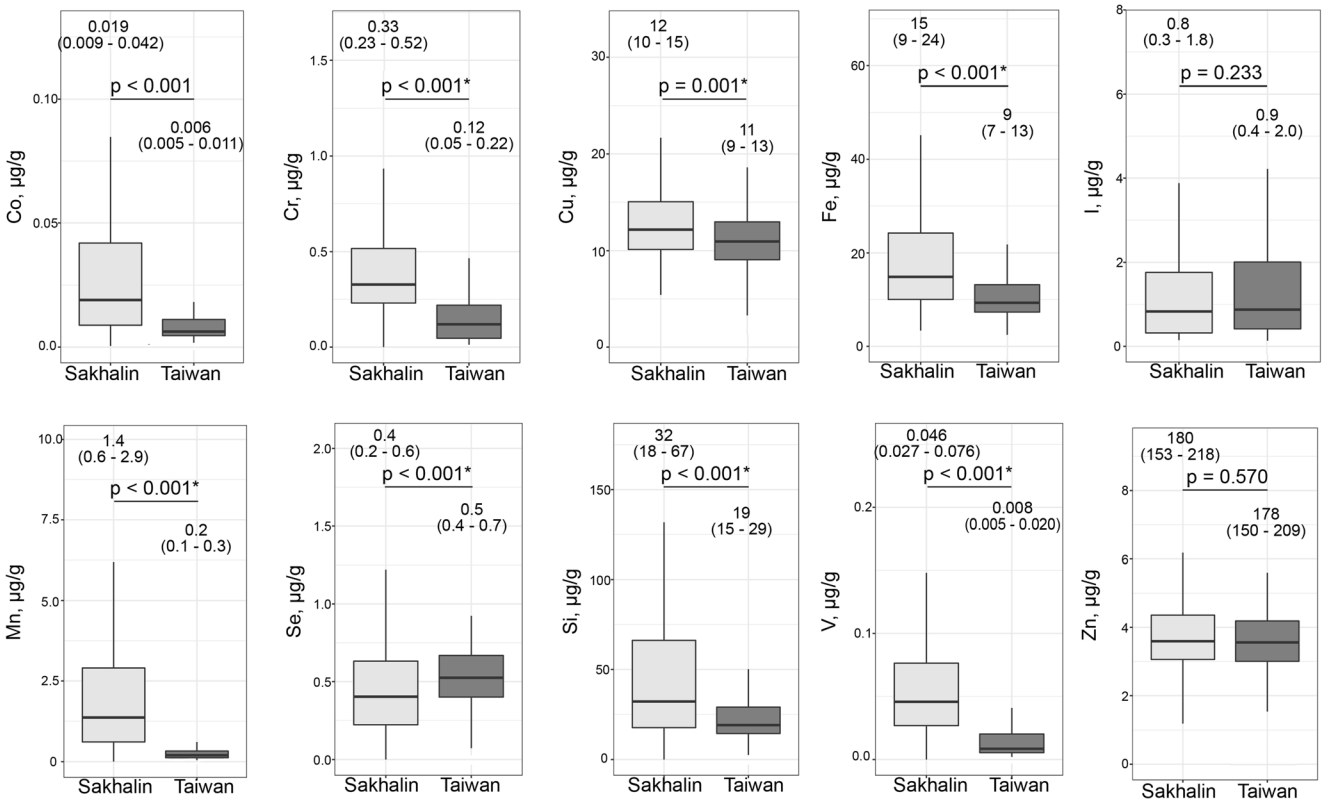
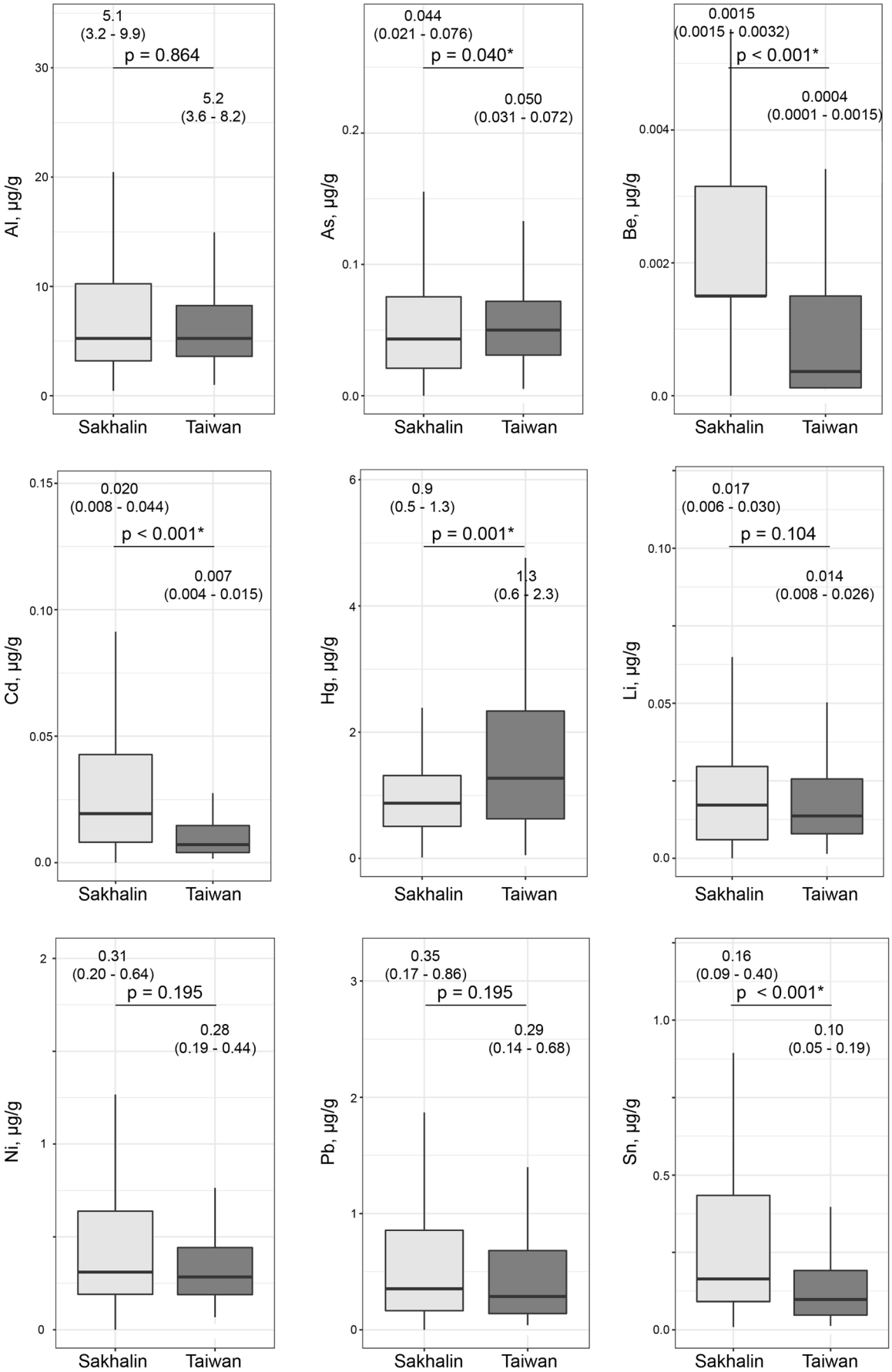


Fig. 1 Hair essential trace element content (µg/g) in inhabitants of Taipei (Taiwan, Republic of China) (dark box) and Yuzhno-Sakhalinsk (Sakhalin, Russia) (light box). Data are expressed as median (line), 25–75 percentile boundaries (box) and non-outlier range. Individual *p* values for group comparisons are provided.

Comparative Analysis of Hair Trace Element Content Between Taipei and Yuzhno-Sakhalinsk Gender Groups

Our data demonstrate that Yuzhno-Sakhalinsk inhabitants are characterized by significantly higher hair essential trace element content (Table 2). In particular, hair Co levels in Sakhalinian women and men were nearly threefold ($p < 0.001$) and twofold ($p < 0.001$) higher than those in examinees from Taipei, respectively. Scalp hair Cr and Fe concentration in Sakhalinian women and men exceeded the values obtained in Taiwanese persons by 158% ($p < 0.001$) and 193% ($p < 0.001$), and 80% ($p < 0.001$) and 27% ($p = 0.019$), respectively. At the same time, hair Cu levels were higher only in men from Yuzhno-Sakhalinsk as compared to the Taiwanese male examinees ($p = 0.003$). Extreme difference was observed in hair concentration of Mn and V between the Taipei and Yuzhno-Sakhalinsk inhabitants. Particularly, the level of Mn in Sakhalinian women was tenfold higher as compared to the respective values in Taiwanese women ($p < 0.001$). Yuzhno-Sakhalinsk male inhabitants were characterized by more than twofold higher levels of Mn in comparison to the respective Taipei group ($p = 0.023$). Similarly, hair V content in Taipei women ($p < 0.001$) and men ($p < 0.001$) was more than six- and fivefold lower than that in Sakhalinian males and females, respectively. It is also notable, that hair Si content in men and women from Yuzhno-Sakhalinsk was 77% ($p < 0.001$) and 65% ($p = 0.009$) higher as compared to the respective Taipei values. Hair I, Se, and Zn levels did not differ significantly between the respective groups from the studied locations.

Gender-specific hair toxic trace element profiles were also characterized by geographical difference (Table 3). In particular, hair Be content in men ($p < 0.001$) and women ($p < 0.001$) from Yuzhno-Sakhalinsk was five- and threefold higher than the respective values obtained in Taipei. Hair Sn levels in Sakhalinian women and men were 72% ($p < 0.001$) and 74% ($p = 0.019$) higher than the respective Taiwanese values. Sakhalinian female and male examinees were also characterized by more than two- ($p < 0.001$) and threefold ($p < 0.001$) higher values of hair cadmium than those in Taiwanese persons. It is notable that the only toxic metal, being higher in Taipei inhabitants, was mercury. In particular, hair Hg content in Taiwanese women and men was higher than the respective Yuzhno-Sakhalinsk values by 25% ($p = 0.063$) and 60% ($p = 0.020$). At the same time, no significant geographical difference in hair Al, As, Li, Ni, and Pb was observed.


Al, µg/g
5.1
(3.2 - 9.9)
p = 0.864
5.2
(3.6 - 8.2)
Sakhalin
Taiwan
As, µg/g
0.044
(0.021 - 0.076)
p = 0.040*
0.050
(0.031 - 0.072)
Be, µg/g
0.0015
(0.0015 - 0.0032)
p < 0.001*
0.0004
(0.0001 - 0.0015)
Cd, µg/g
0.020
(0.008 - 0.044)
p < 0.001*
0.007
(0.004 - 0.015)
Hg, µg/g
0.9
(0.5 - 1.3)
p = 0.001*
1.3
(0.6 - 2.3)
Li, µg/g
0.017
(0.006 - 0.030)
p = 0.104
0.014
(0.008 - 0.026)
Ni, µg/g
0.31
(0.20 - 0.64)
p = 0.195
0.28
(0.19 - 0.44)
Pb, µg/g
0.35
(0.17 - 0.86)
p = 0.195
0.29
(0.14 - 0.68)
Sn, µg/g
0.16
(0.09 - 0.40)
p < 0.001*
0.10
(0.05 - 0.19)

◀ **Fig. 2** The level of hair toxic trace elements (μg/g) in Taipei (Taiwan, Republic of China) (dark box) and Yuzhno-Sakhalinsk (Sakhalin, Russia) (light box) inhabitants. Data are expressed as median (line), 25–75 percentile boundaries (box) and non-outlier range. Individual p values for group comparisons are provided.

Discussion

The obtained results are generally in agreement with the existing data on hair trace element content in continental Russia. In particular, data on hair content of Co, Cr, Cu, Fe, Mn, Se, V, Zn [11], Al, As, Be, Bi, Cd, Hg, Li, Ni, Pb, Sn, and Sr [12] in Yuzhno-Sakhalinsk inhabitants are in agreement with the Russian reference values. At the same time, it is notable that the content of Co, Fe, Se, V, Al, Be, Cd, Li, and Ni in hair of persons living in Orenburg (South Urals, Continental Russia) was higher as compared to that in Yuzhno-Sakhalinsk. Oppositely, Yuzhno-Sakhalinsk inhabitants were characterized by increased hair concentration of I, Hg, and Sn [17]. The observed differences may occur due to high proportion of dietary seafoods being a source of iodine [18], mercury [19], and tin [20] in Yuzhno-Sakhalinsk inhabitants in contrast to Orenburg inhabitants, who are characterized by extremely low proportion of seafood in diets.

The detected levels of hair trace element content in Taipei inhabitants were significantly different from those in the continental regions of China. Particularly, hair concentration of Cr, Mn, As, Cd, Ni, and Pb in the examinees living in Guangdong province exceeded those in Taiwan. Oppositely, hair mercury content was lower than in Taipei inhabitants [21]. Hair levels of Cr, Cu, Mn, Zn, Ni, and Pb were also increased in Nanking city as compared to the obtained values in Taipei [21]. Persons living in Shanshi were also characterized by elevated hair concentration of Cr, Cu, Fe, Mn, Se, and Pb, whereas Zn levels were lower than the obtained Taipei values [22]. Finally, the observed values for hair Co and V were lower than that observed in Chinese adults [22]. As in the case of Yuzhno-Sakhalinsk, increased hair mercury content in Taipei inhabitants in comparison to the persons living in continental China may occur due to increased consumption of seafood being a significant source of mercury [19], arsenic [23], and selenium [24]. At the same time, higher hair content of both essential and toxic trace elements in continental China inhabitants (Guangdong, Shanxi, and Jiangsu provinces) may be a consequence of more intensive environmental pollution than in Taiwan as assessed by the level of pollutants emitted into the air (SO_2, NO_x, CO) [25].

Taking into account the correspondence between the respective national reference values of hair trace element content and the ones obtained from Taiwan and Sakhalin inhabitants, it is proposed that the observed differences in hair trace element content may mediate certain metabolic differences between the locations, without being toxic.

Generally, the level of hair essential and toxic trace elements was significantly higher in Sakhalin inhabitants with an exception for mercury, selenium, and arsenic. These differences may be related to geological, environmental, and dietary factors. The observed elevation of hair trace element content in persons living in Sakhalin may be indicative of increased metal exposure from the environment. Sakhalin is an industrial center with developed heavy industry like oil, gas, coal, and energy production [26]. Earlier data indicate that anthropogenic industrial sources contribute largely to trace element

Table 3 Hair essential trace element content (μg/g) in men and women living in Taipei (Taiwan, Republic of China) and Yuzhno-Sakhalinsk (Sakhalin, Russia)

Element	Taipei		Yuzhno-Sakhalinsk	
	Women ($n = 94$)	Men ($n = 46$)	Women ($n = 186$)	Men ($n = 67$)
Zn	184.7 (152.5–218.5)	165.5 (138.5–194.7)	181.9 (153.0–218.1)	167.8 (151.5–212.5)
Si	18.48 (13.88–27.93)	20.05 (16.59–32.14)	32.02 (17.16–67.23)[a]	33.33 (19.70–64.21)[b]
Cu	11.22 (9.75–13.03)	10.27 (8.77–12.33)	11.95 (10.09–15.02)	12.28 (10.23–15.06)[b]
Fe	8.947 (7.287–12.063)	10.68 (7.43–15.69)	15.51 (9.92–24.95)[a]	14.35 (10.34–21.77)[b]
I	0.924 (0.476–2.480)	0.773 (0.372–1.683)	0.749 (0.303–1.839)	0.943 (0.391–1.650)
Se	0.478 (0.386–0.667)	0.578 (0.484–0.665)	0.370 (0.201–0.570)[a]	0.520 (0.335–0.681)[c]
Mn	0.165 (0.111–0.259)	0.292 (0.165–1.764)[a]	1.729 (0.876–3.524)[a]	0.783 (0.411–1.497)[b,c]
Cr	0.120 (0.044–0.200)	0.150 (0.057–0.260)	0.310 (0.210–0.460)[a]	0.440 (0.270–0.670)[b,c]
V	0.007 (0.005–0.015)	0.011 (0.006–0.026)	0.042 (0.025–0.066)[a]	0.057 (0.038–0.094)[b,c]
Co	0.006 (0.005–0.010)	0.007 (0.005–0.013)	0.022 (0.010–0.051)[a]	0.012 (0.008–0.032)[b,c]

Data presented as median and the respective 25–75 percentile boundaries

[a] Significant difference in comparison to group 1 (Taiwanese women) at $p < 0.05$;

[b] Significant difference in comparison to group 2 (Taiwanese men) at $p < 0.05$;

[c] Significant difference in comparison to group 3 (Sakhalin women) at $p < 0.05$

Table 4 Toxic trace element concentration (μg/g) in scalp hair of Taipei (Taiwan, Republic of China) and Yuzhno-Sakhalinsk (Sakhalin, Russia) inhabitants

Element	Taipei		Yuzhno-Sakhalinsk	
	Women ($n = 94$)	Men ($n = 46$)	Women ($n = 186$)	Men ($n = 67$)
Al	5.138 (3.305–8.245)	5.474 (4.341–8.129)	4.784 (2.850–9.651)	7.248 (4.240–12.62)[c]
Hg	1.019 (0.496–2.102)	1.603 (1.063–2.402)	0.804 (0.497–1.255)	1.030 (0.608–1.715)[b,c]
Ni	0.276 (0.187–0.430)	0.312 (0.197–0.448)	0.324 (0.199–0.674)	0.275 (0.171–0.564)
Pb	0.202 (0.113–0.430)	0.574 (0.280–1.522)[a]	0.278 (0.141–0.562)	0.909 (0.408–1.682)[c]
Sn	0.099 (0.043–0.190)	0.092 (0.058–0.200)	0.169 (0.088–0.640)[a]	0.160 (0.098–0.240)[b]
As	0.039 (0.021–0.056)	0.070 (0.059–0.100)[a]	0.021 (0.021–0.057)	0.075 (0.048–0.110)[c]
Li	0.013 (0.008–0.023)	0.014 (0.008–0.028)	0.017 (0.006–0.030)	0.016 (0.006–0.029)
Cd	0.006 (0.004–0.011)	0.009 (0.004–0.022)	0.015 (0.007–0.035)[a]	0.029 (0.017–0.057)[b,c]
Be	0.0003 (0.0001–0.0015)	0.0005 (0.0001–0.0014)	0.0015 (0.0015–0.0018)[a]	0.0015 (0.0015–0.0035)[b]

[a] Significant difference in comparison to group 1 (Taiwanese women) at $p < 0.05$

[b] Significant difference in comparison to group 2 (Taiwanese men) at $p < 0.05$

[c] Significant difference in comparison to group 3 (Sakhalin women) at $p < 0.05$

emissions [27]. In particular, it has been demonstrated that different types of fuels contain significant amounts of trace elements [28], and coal and oil combustion may result in metal emission into the environment [29]. Finally, it has been shown that metal content in snow cover of South Sakhalin (Sea of Okhotsk) largely depend on anthropogenic sources [30].

In contrast, the main directions of Taiwan manufacturing industry are metal and machinery industries, information and communications technology industry, chemical industry, and consumer goods industries [31]. One can suppose that the higher prevalence of heavy industry in Yuzhno-Sakhalinsk in comparison to Taipei may result in higher rate of trace element pollution. This supposition is at least partially confirmed by higher values of atmospheric emissions from Russian Far East than that from Taiwan [32]. However, this excellent work did not assess specific emissions from Sakhalin, being only a part of Far East region of Russia.

The obtained data indicate that only mercury, arsenic, and selenium content were increased in hair of Taiwanese inhabitants. We hypothesize that the observed situation may occur due to increased fish consumption in Taiwan as compared to Sakhalin [33]. Earlier data indicate that fish consumption is one of the leading sources of mercury in humans [19]. Moreover, it has been shown that excessive fish consumption results in increased hair mercury content [34]. It has been also demonstrated that fish consumption is the main contributor to hair mercury levels in eastern China [35]. High rate of Hg emissions in continental China (500–700 tons annually) [36] may also at least partially contribute to increased hair Hg levels in Taiwan inhabitants through seasonal wind and contamination of local seafoods. High As levels in groundwater in Taiwan were detected [37], being a potential factor of increased hair As content. Moreover, a high proportion of semi-conductor industry which uses arsenic as dopants is also located in Taiwan [38]. Certain studies have also demonstrated increased soil As and Ni content in Taiwan [39].

The obtained data also demonstrated the impact of gender on trace element levels in Yuzhno-Sakhalinsk and Taipei inhabitants. It has been proposed that gender is the key factor affecting hair trace element content [40]. In particular, earlier data demonstrate that women accumulate more Co than men that may be at least partially associated with physiological iron loss [41]. Gender had a significant impact on hair Mn levels. In particular, men had significantly higher hair Mn levels in Taiwan, whereas in Sakhalin maximal levels were detected in women. The earlier studies have also demonstrated certain contradictions in hair Mn levels with respect to gender. In particular, the markers of Mn status were significantly higher in women from Bangladesh [42] or China [43], whereas the study from Canary Islands [44] failed to detect any significant difference.

It is notable that in the case of certain trace elements, geographical location significantly affected gender-specific features. We propose that different exposure levels (as assessed by hair trace element content) may significantly affect gender-specific metabolic pathways. Another factor that can significantly affect metabolism resulting in different trace element patterns is ethnicity [45].

Elevated hair toxic trace element content in Sakhalinian men as compared to women may occur due to higher rate of outdoor activities in men [40]. At the same time, gender-specific metabolic pathways may also affect toxic trace element handling [46].

Finally, gender difference in hair trace element content was more expressed in Sakhalin inhabitants. Taking into account the higher rate of metal emissions in Sakhalin, increased

outdoor activities in men may significantly increase the gender difference.

Conclusions

The obtained data indicate that persons living in Yuzhno-Sakhalinsk are characterized by significantly higher hair content of essential (Co, Cr, Cu, Fe, Mn, Si, and V) and toxic (Be, Cd, Sn) trace elements, whereas the maximal levels of hair mercury, arsenic, and selenium were observed in the examinees living in Taiwan. Hypothetically, the higher hair metal content in Sakhalin inhabitants may occur due to intensive development of heavy industry in Sakhalin and increased metal emissions. In turn, elevated As, Hg, and Se levels in Taiwan inhabitants may be a consequence of higher fish consumption. Further investigations involving higher number of examinees should be performed to investigate the impact of certain sources on hair trace element profiles in Taiwan and Sakhalin.

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Compliance with Ethical Standards The protocol of the study was approved by the Local Ethics Committee, and procedures were performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All examinees gave their informed consent prior to the inclusion in the study.

Conflict of Interest The authors declare that they have no conflict of interest.

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