Journal of Elementology ISSN 1644-2296

Skalnaya M.G., Tinkov A.A., Demidov V.A., Serebryansky E.P., Nikonorov A.A., Skalny A.V. 2016. *Hair ultra-trace elements in relation to age and body mass index in adult women.* J. Elem., 21(1): 211-220. DOI: 10.5601/jelem.2015.20.3.924

HAIR ULTRA-TRACE ELEMENTS IN RELATION TO AGE AND BODY MASS INDEX IN ADULT WOMEN

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Abstract

The problem of relationships between the ultra-trace element content in a human organism and obesity has been poorly studied thus far. The primary objective of the current research has been to investigate the association between hair ultra-trace element content, body mass index and age in adult women. 1281 adult women participated in the survey. Hair ultra-trace element content (Ag, Au, Ga, Ge, La, Pt, Rb, Sb, Tl, W, Zr) was assessed by inductively coupled plasma mass spectrometry using a NexION 300D+NWR213 apparatus (Perkin-Elmer, USA). No significant association between the hair Ag, Au, Ga, Ge, La, and Pt content and body mass index (BMI) values was observed. The hair Rb levels in normal weight, overweight and obese women exceeded the respective values in underweight females by 33 ($p < 0.001$), 105 ($p < 0.001$), and 314% ($p < 0.001$). The hair Sb content in obese persons was 38 ($p < 0.001$), 38 ($p < 0.001$), and 22% ($p = 0.022$) higher in comparison to the values observed in underweight, normal weight and overweight subjects. A twofold increase in the hair Tl content was observed in obese females in comparison to the underweight ($p < 0.001$) and normal weight ones ($p = 0.037$). It has been observed that obese women were characterized by 33% higher hair W levels in comparison to the underweight (p < 0.001) and normal weight group values ($p = 0.002$). The results of correlation and multiple regression analyses partially confirmed these findings and indicated that hair Rb values were characterized by the closest association with the age and BMI. To our knowledge, it is the first report on a relationship between the hair ultra-trace element content and increased body weight. The data may be used as reference values of the content of ultra-trace element in hair of women with different body mass index. However, additional experimental and

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clinical studies are required to explore the mechanisms of such an association.

Keywords: ultra-trace elements, body mass index, obesity, metals, rubidium, tungsten, hair.

INTRODUCTION

In a healthy human body, ultra-trace elements are present in extremely low quantities. Some ultra-trace elements originate from natural sources, occurring in high levels in the Earth's crust (Zr, Ga, La), while others may enter human organism due to the development of industry (Ge, Sb, Au, Ag) (Schroeder, Darrow 1972). Moreover, several ultra-trace elements are widely used in medicine (Au, Pt) (Krachler, Irgolic 1999). Despite an extremely low level of ultra-trace elements in an organism, their accumulation due to excessive exposure may have adverse health effects (Goyer, Clarkson 1996). For example, thallium is claimed to be one of the most toxic ultra-trace elements due to the inhibition of certain enzymes, coenzymes and proteins it causes (Galván-Arzate, Santamaría 1998).

It has been proposed earlier that environmental pollution, including metal contamination, plays a significant role in the epidemic of obesity (Baillie-Hamilton 2002). Oxidative stress is suspected to play a significant role in obesity pathogenesis (Matsuzawa-Nagata et al. 2008). At the same time, it has been demonstrated that a number of ultra-trace metals like thallium (Kiliç, Kutlu 2010), platinum (Carozzi et al. 2010), silver (Cortese-Krott et al. 2011), gold (Rigobello et al. 2008), gallium (Bériault et al. 2007) or antimony (Tirmenstein et al. 1995) possess prooxidant properties. Consequently, it may be expected that ultra-trace elements could also be associated with body weight index (Padilla et al. 2010). However, data regarding this aspect of ultra-trace element toxicology are insufficient.

Therefore, the primary objective of the current research has been to investigate the relationship between hair ultra-trace element content, body mass index and age in adult women.

MATERIAL AND METHODS

In total, 1281 adult women participated in the current survey. The research was approved by the Local Ethics Committee of the Institute of Bioelementology (Orenburg State University). All the examinees gave their informed consent prior to the inclusion into the study. The selection of the participants was based on exclusion criteria. The exclusion criteria in the present study were: 1) acute traumas and posttraumatic period; 2) metabolic diseases; 3) menstruation; 4) specific dietary habits; 5) smoking; 6) the use of hormonal medications (including combined oral contraceptives); 7) occupational exposure to metals; 8) metal implants; 9) synthetic hair dyes. All examinees were also subdivided into four subgroups depending on the body mass index values (WHO). The first group of females with BMI < 18.5 was considered to be underweight. The second group was characterized by normal weight (18.5 < BMI > 25), while the third group of the examinees (25 < BMI > 30) was classified as overweight. The examinees with BMI values over 30.0 were regarded as obese (IV group).

All participants washed hair at the day of sample collection. Occipital scalp hair was collected in the quantity of 0.1 gram. Only proximal parts of hair strands (0.5-1.0 cm) were taken for analysis in order to diminish possible environmental contamination of the samples. Before the analysis, hair samples were washed with acetone and then rinsed thrice with deionized water. Afterwards, hair samples were dried at 60°C on air. The samples were digested with concentrated HNO_3 at 180°C in a Berghof speedwave four system. Ultra-trace element (Ag, Au, Ga, Ge, La, Pt, Rb, Sb, Tl, W, Zr) content (μg g^{-1}) in the samples obtained was assessed by inductively coupled plasma mass spectrometry using a NexION 300D+NWR213 (Perkin-Elmer, USA). Calibration was performed in accordance with the manufacturer's specifications. Standards containing 0.5, 5, 10, and 50 μg dm^{-3} of ultra-trace elements were prepared from Universal Data Acquisition Standards Kit (PerkinElmer Inc., Shelton, CT 06484, USA) by dilution with distilled deionized water and acidification with 1% HNO_3. An internal online standardization using yttrium-89 isotope was performed in order to take into account the incomplete conformity in acidity and viscosity between sample and calibrating solution matrices. The certified reference material of human hair GBW09101 (Shanghai Institute of Nuclear Research, Academia Sinica, China) containing La (0.029 μg g^{-1}) and Sb (0.12 μg g^{-1}) was used for laboratory quality control. The recovery rates for these metals exceeded 85%. No other standard reference material of human hair containing all analyzed ultra-trace elements exists to date.

Statistical processing of data was performed using Statistica 10.0 software (Statsoft). Data distribution was evaluated by the Shapiro-Wilk test. The distribution achieved was abnormal. Consequently, the data were reported as median values and the respective 25 and 75 percentile boundaries. As the distribution was not Gaussian, all variables required log transformation to approximate a normal distribution. Natural logarithms were used for further statistical analyses. One-way Anova was used to estimate the effect of increased BMI on hair ultra-trace element content. Significant differences between group values were assessed using the Fisher LSD-test. The Pearson's correlation coefficient was used for correlation analysis. Age, height, weight and BMI were used as dependent variables in multiple regression analyses. Independent variables were hair ultra-trace element concentrations. The data were reported as standardized regression coefficients (β), partial correlation coefficients and the respective *p*-values. The level of significance was set as $p < 0.05$ for all analyses.

RESULTS

The results indicate a strong significant association between BMI and age values (Table 1). In particular, age values in normal weight, overweight and obese women were significantly higher in comparison to the underweight ones.

Statistical analysis failed to reveal any significant changes in the hair content of silver, gold, gallium, germanium, lanthanum and platinum in relation to BMI values in the examinees. The most expressed BMI-associated changes were observed in the hair rubidium content. In particular, the hair Rb levels in normal weight, overweight, and obese women exceeded the respective values in underweight females by 33 ($p < 0.001$), 105 ($p < 0.001$), and 314% ($p < 0.001$). The hair antimony content in obese persons was 38 ($p < 0.001$), 38 ($p < 0.001$) and 22% ($p = 0.022$) higher in comparison to the values observed in underweight, normal weight and overweight examinees. A twofold increase in the hair thallium content was observed in obese females in comparison to the underweight ($p < 0.001$) and normal weight ones ($p = 0.037$). It has been observed that obese women were characterized by 33% higher hair tungsten levels in comparison to the underweight ($p < 0.001$) and normal weight group values ($p = 0.002$). Noteworthy, the overall tendency to a BMI-related change in the hair rubidium, antimony, thallium and tungsten content was significant in accordance with one-way Anova.

Correlation analysis (Table 2) has revealed a significant positive relationship between the age values and hair silver, lanthanum, and rubidium content. An inverse association between the scalp hair Zr and age was also detected. Despite the significance of the observed relationships, the statistical dependence between the age values and hair Ag, La, and Zr content was weak. The hair levels of La, Rb, Sb, Tl, and W were characterized by a significant direct relationship with the body weight values. At the same time, the highest correlation coefficients were observed for the hair rubidium-body weight interaction. The hair platinum levels significantly correlated with the body height although the interaction was weak. The BMI values were characterized by a positive relationship with the hair rubidium, antimony, thallium, and tungsten content, with the highest correlation coefficients observed for the rubidium-BMI interaction.

The results of multiple regression (Table 3) analyses partially confirmed the results of the linear correlation analysis. In particular, a direct dependence between hair silver, rubidium and antimony was demonstrated. At the same time, the interaction between the age and hair zirconium was inverse.

Table 1

Hair ultra-trace element content in relation to body mass index, age, height and weight values in adult women

Group (n)	Underweight (137)	Normal weight (873)	Overweight (187)	Obese (84)	p
Age, years	28.2(25.2-33.3)	34.6(28.9-41.7) *	41.6(33.9-52.8) *,**	48.3(38.7-54.4) *,**,***	< 0.001
Weight (kg)	50.0(47.0-53.0)	59.0(55.0-63.0) *	74.0(70.0-80.0) *,**	90.0(83.0-96.0) *,**,***	< 0.001
Height (cm)	168.0(164.0-172.0)	167.0(164.0-170.0)	165.0(161.0-170.0) *,**	164.5(160.5-170.0) *,**	< 0.001
BMI (kg m^{-2})	18.0(17.4-18.3)	20.9(19.6-22.7) *	26.8(25.8-28.2) *,**	32.4(30.6-35.0) *,**,***	< 0.001
Ag (μg g^{-1})	0.069(0.033-0.128)	0.063(0.028-0.161)	0.055(0.026-0.157)	0.063(0.029-0.171)	0.990
Au (μg g^{-1})	0.044(0.026-0.124)	0.057(0.025-0.128)	0.057(0.025-0.143)	0.062(0.027-0.136)	0.703
Ga (μg g^{-1})	0.006(0.005-0.007)	0.006(0.005-0.008)	0.006(0.005-0.008)	0.006(0.005-0.008)	0.347
Ge (μg g^{-1})	0.006(0.003-0.008)	0.006(0.003-0.009)	0.006(0.002-0.009)	0.006(0.002-0.008)	0.814
La (μg g^{-1})	0.003(0.002-0.006)	0.003(0.002-0.007)	0.003(0.002-0.008)	0.003(0.002-0.007)	0.226
Pt (μg g^{-1})	0.001(0.001-0.001)	0.001(0.001-0.001)	0.001(0.001-0.001)	0.001(0.000-0.001)	0.627
Rb (μg g^{-1})	0.021(0.012-0.038)	0.028(0.015-0.064) *	0.043(0.020-0.118) *,**	0.087(0.034-0.260) *,**,***	< 0.001
Sb (μg g^{-1})	0.008(0.005-0.013)	0.008(0.006-0.013)	0.009(0.006-0.016)	0.011(0.007-0.018) *,**,***	0.001
Tl (μg g^{-1})	0.0001(0.0001-0.0002)	0.0001(0.0001-0.0003) *	0.0001(0.0001-0.0003) *	0.0002(0.0001-0.0003) *,**	< 0.001
W (μg g^{-1})	0.003(0.001-0.004)	0.003(0.002-0.005)	0.003(0.002-0.005) *	0.004(0.002-0.006) *,**	0.002
Zr (μg g^{-1})	0.052(0.029-0.182)	0.060(0.030-0.132)	0.051(0.028-0.132)	0.062(0.029-0.160)	0.366

n – number of examinees in a group; * significant difference in relation to the underweight group; ** significant difference in relation to the normal weight group; *** significant difference in relation to the overweight group; p – p values by one-way Anova for global tendency

Table 2

Pearson's coefficients of correlation between hair ultra-trace element content (μg g^{-1}) and age, height, weight and BMI values in adult women

Parameter	Age, years	Weight (kg)	Height (cm)	BMI (kg m^{-2})
Ag (μg g^{-1})	*r* = 0.070 *p* = 0.012	*r* = 0.025 *p* = 0.368	*r* = 0.026 *p* = 0.354	*r* = 0.015 p = 0.595
Au (μg g^{-1})	*r* = -0.015 *p* = 0.599	*r* = 0.023 *p* = 0.404	*r* = -0.001 *p* = 0.967	*r* = 0.025 p = 0.379
Ga (μg g^{-1})	*r* = -0.031 *p* = 0.271	*r* = 0.012 *p* = 0.678	*r* = -0.021 *p* = 0.464	*r* = 0.021 p = 0.457
Ge (μg g^{-1})	*r* = 0.037 *p* = 0.184	*r* = 0.015 *p* = 0.598	*r* = 0.028 *p* = 0.310	*r* = 0.003 p = 0.913
La (μg g^{-1})	*r* = 0.062 *p* = 0.028	*r* = 0.066 *p* = 0.018	*r* = 0.034 *p* = 0.231	*r* = 0.054 *p* = 0.054
Pt (μg g^{-1})	*r* = 0.025 *p* = 0.380	*r* = -0.006 *p* = 0.842	*r* = 0.058 *p* = 0.037	*r* = -0.031 *p* = 0.271
Rb (μg g^{-1})	*r* = 0.264 *p* < 0.001	*r* = 0.267 *p* < 0.001	*r* = -0.042 *p* = 0.130	*r* = 0.294 *p* < 0.001
Sb (μg g^{-1})	*r* = 0.002 *p* = 0.944	*r* = 0.110 *p* < 0.001	*r* = 0.018 *p* = 0.532	*r* = 0.106 *p* < 0.001
Tl (μg g^{-1})	*r* = 0.043 *p* = 0.126	*r* = 0.113 *p* < 0.001	*r* = -0.016 *p* = 0.567	*r* = 0.124 *p* < 0.001
W (μg g^{-1})	*r* = 0.041 *p* = 0.139	*r* = 0.082 *p* = 0.003	*r* = -0.054 *p* = 0.055	*r* = 0.107 *p* < 0.001
Zr (μg g^{-1})	*r* = -0.085 *p* =0.002	*r* = 0.003 *p* = 0.927	*r* = -0.022 *p* = 0.439	*r* = 0.012 *p* = 0.670

r – correlation coefficients; *p* – individual *p* values for the interaction; the value of $p < 0.05$ is considered to be significant

No significant association was observed between the hair lanthanum content and age values in women. In contrast to the linear correlation results, multiple regression analysis indicated a significant association with body weight only for the hair rubidium content. In accordance with the linear correlation, a positive interdependence was observed between scalp hair platinum content and body height. Only the hair rubidium and tungsten content was significantly associated with the BMI values in women in accordance with multiple regression analysis.

Table 3

Regression models with age, height, weight and BMI as dependent variables

Parameter	Age			Weight			Height			BMI		
	β	PC	p^*	β	PC	p^*	β	PC	p^*	β	PC	p^*
Ag (μg g^{-1})	0.102	0.091	0.001	-0.021	-0.019	0.507	0.019	0.016	0.563	-0.030	-0.027	0.341
Au (μg g^{-1})	-0.053	-0.049	0.081	-0.031	-0.028	0.313	-0.007	-0.006	0.825	-0.029	-0.027	0.340
Ga (μg g^{-1})	-0.048	-0.049	0.083	-0.026	-0.026	0.348	-0.018	-0.017	0.544	-0.020	-0.020	0.480
Ge (μg g^{-1})	0.017	0.018	0.528	-0.007	-0.007	0.804	0.024	0.023	0.404	-0.017	-0.018	0.527
La (μg g^{-1})	0.013	0.013	0.651	-0.006	-0.006	0.832	0.048	0.044	0.119	-0.027	-0.026	0.357
Pt (μg g^{-1})	0.017	0.018	0.529	-0.025	-0.025	0.382	0.062	0.059	0.034	-0.052	-0.052	0.063
Rb (μg g^{-1})	0.310	0.278	< 0.001	0.253	0.227	< 0.001	-0.061	-0.054	0.054	0.287	0.258	< 0.001
Sb (μg g^{-1})	-0.111	-0.092	0.001	0.052	0.043	0.128	0.034	0.027	0.340	0.039	0.033	0.246
Tl (μg g^{-1})	-0.031	-0.032	0.260	0.039	0.039	0.164	0.008	0.007	0.797	0.037	0.038	0.181
W (μg g^{-1})	0.043	0.041	0.144	0.041	0.038	0.170	-0.063	-0.057	0.044	0.069	0.066	0.020
Zr (μg g^{-1})	-0.120	-0.116	< 0.001	-0.039	-0.038	0.178	-0.027	-0.025	0.371	-0.029	-0.028	0.315
Multiple R	0.322			0.281			0.117			0.315		
R^2	0.104			0.079			0.014			0.099		
Adjusted R^2	0.096			0.071			0.005			0.091		
p	< 0.001			< 0.001			< 0.001			< 0.001		

β – standardized regression coefficients; PC – partial correlation coefficient; p^* – individual p value; p – p value for the model

DISCUSSION

The current data on the ultra-trace element content in hair agree with previous observations. In particular, scalp hair concentrations of silver, gold, gallium, germanium, lanthanum, antimony, thallium, tungsten and zirconium are within the previously estimated reference ranges (Rodushkin, Axelsson 2000, Goulle et al. 2005, Chojnacka et al. 2010). At the same time, we detected that the hair platinum content in all examined women exceeded the reference values (Rodushkin, Axelsson 2000; Goulle et al. 2005). The hair rubidium content in adult women exceeded the reference limits obtained by Goulle and the co-workers (Goulle et al. 2005).

We have estimated that the hair silver, rubidium, antimony, and zirconium content increased in an age-dependent manner in adult women. This finding is partially in agreement with a previous observation of an age-related increase in hair zirconium in aged rats (Ambeskovic et al. 2013). At the same time, no significant association between hair silver, antimony and rubidium levels and age were found (Ambeskovic et al. 2013). Our study has also failed to reveal any significant change in hair lanthanum, which is in contradiction to an earlier study (Wei et al. 2013).

The present study has demonstrated that only the hair rubidium and tungsten content was significantly associated with increased BMI. Our research data are contradictory to the previous work of Padilla and colleagues (Padilla et al. 2010). In particular, those authors indicated that the hair thallium content was positively associated with BMI values, whereas our data did not prove it.

The role of an increased rubidium and tungsten content in obesity is not clear. We suppose that the increased hair levels of rudibium and tungsten in overweight and obese subjects may result from increased food consumption. In particular, it has been shown that food and especially beverages contain high concentrations of both rubidium (Anke, Angelow 2004) and tungsten (Gbaruko, Igwe 2007). Taking into account the direct association between obesity development and the intake of beverages (Nielsen, Popkin 2004), such a mechanistic approach may explain elevated hair levels of Rb and W.

While discussing the biological effects of rubidium, it is essential to mention its physicochemical similarity to potassium (Kupriyanov 2013). It has been shown that rubidium may replace potassium in a number of physiological processes (Kupriyanov 2013). Interestingly, a significant association between hair potassium and anthropometric parameters in adult women (Skalnaya, Demidov 2007) and in rats with experimental obesity (Tinkov et al. 2014) was observed earlier. However, the mechanism of those relationships is unclear.

Previous studies indicated that tungsten compounds may be used in medicine (Jelikić-Stankov et al. 2007). In particular, it has been demonstrated that administration of tungstate decreased body weight and adiposity in obese rats through increased thermogenesis and lipid oxidation (Claret et al. 2005). Taking into account these indications, it is problematic to propose a mechanism explaining the observed association between the hair tungsten content and obesity.

Generally, the current results indicate that hair rubidium is positively associated with BMI and age values in adult women. However, additional experimental and clinical studies are required to highlight the mechanisms of such an association. To our knowledge, it is the first report on relationships between hair ultra-trace element content and increased body weight. The data presented above may be used as reference values of the hair ultra-trace element content in women with different body mass index.

Conflict of interest

The authors declare no conflict of interest in relation to the manuscript.

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