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Arsenic and heavy metal concentrations in human hair from urban areas

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Abstract

Background: As concentrations of heavy metals in hair can reflect both metals exposure and intake concentrations, hair sample analysis is widely applied in forensic sciences, evaluation of environmental or occupational exposure and other studies. The aim of this study was to evaluate the concentrations of As, Cd, Pb, Cr, Cu, Co, Mn, Zn, Fe and Ni in the scalp hair of an urban population from Kermanshah in western Iran.

Methods: In the present research, 30 points of the city were selected for human scalp hair sampling. Samples were taken from healthy inhabitants (aged 6 to 46 years) in Kermanshah city. Multivariate analysis method was applied to distinguish the anthropogenic and natural sources of heavy metals. Levels of elements in the scalp hair were measured by ICP-MS.

Results: The mean concentrations of Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb and As were 33.53 ± 9.05, 27.98 ± 7.77, 203.18 ± 22.31, 1.94 ± 0.85, 18.44 ± 3.40, 107.11 ± 22.56, 119.21 ± 10.52, 0.97 ± 0.36, 60.27 ± 13.84, and 0.34 ± 0.51 μg/g in the urban area, respectively. The highest concentration of all elements was found in the age group of 31-40 and 41-50 years except Fe, the maximum concentration of which was found in the age group of 6-20 years. Significant differences were found between smokers and non-smokers.

Conclusion: Comparison of the heavy metals concentrations in the scalp hair of this area showed that the concentrations of the elements were clearly higher than those reported in other studies. However, the high concentrations of the elements in hair indicated that the inhabitants in the urban areas of Kermanshah might be at risk of exposure to high levels of toxic elements.

Keywords: Scalp hair, Metals, Arsenic, Urban areas, Principal component analysis

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Introduction

Pollution associated with heavy metals and the resultant deleterious health effects on humans following exposure, have provided some motivations for global research efforts. Although few heavy metals are vital to human health, exposure to the elevated levels of these heavy metals can lead to deleterious effects (1). For example, long-term exposure to lead can cause irreversible harm to fetal growth, abnormal hemoglobin synthesis and anemia, hypertension, kidney damage, abortion, nervous system disorders, brain damage, child's decreased ability of learning, and behavioral disorders in children, such as aggression and hyperactivity (2). In addition, it can lead to damages to the cardiovascular system, skin, nervous system, kidneys, and the hematopoietic system (3). Studies indicate that the analysis of contaminants in the environment is not enough for determining the health risks, as the real degree of heavy metals pollution can change widely in a certain district. Hence, biomonitoring of human exposure to heavy metals is the favorable option for researches.

For biomonitoring objects, many different biomarkers such as blood, blood plasma or serum, saliva, urine, nails and hair have been used. All these biomarkers have specified disadvantages. Low levels of most heavy metals are rapidly removed from the blood after chronic and sub-chronic exposures, therefore, in some cases, urine and blood would not show the exposure. In addition, nails and hair are accumulating the pollutants for long periods, allowing for complete evaluation of environmental and occupational exposures (4). Hair is a protein component with a very low metabolic activity and includes a 'record' of metabolic processes in the organism for a long term (3). For many years, hair element analysis has been observed to play an important role in the heavy metals monitoring and has been regarded as useful biomarkers according to the Environmental Protection Agency (EPA) (5). It is worth mentioning that human hair has been introduced by the World Health Organization (WHO) and the EPA to evaluate the effects of various toxic elements on human health (6). Human hair has been used as a biological indicator for heavy metals monitoring in the environmental and occupational exposures, since it is easy to access for sampling, the method is minimally invasive, its store and transport is convenient, and is less hazardous to handle. Besides, hair tissue can be a beneficial evaluation tool as the hair contaminant levels reflect long exposure period (weeks to years depending on the nature of contaminant) (7). Numerous papers have studied the concentration of heavy metals in the human hair to investigate their potential risk to human health (8--15). Studies in this field have indicated that human scalp hair can record the concentration and variation of heavy metals in the body burden over a long period of time (16). Also, these studies showed that the levels of heavy metals in the human hair are associated with many factors, such as environmental factors, sex, age, local resident health differences, eating habits, ethnicity, and analytical method. Despite these numerous reports, the heavy metals concentrations derived from hair has varied considerably, across different areas and populations (10). As urban areas have high concentrations of heavy metals, in this study, the selected elements in human hair of the urban area of Kermanshah city were evaluated. In Kermanshah, there are many sources of pollution such as dust phenomenon, large population, development of industrial centers, and the existence of various sources of urban pollution responsible for the presence of heavy metals in water, food and air. Based on the above- mentioned reasons, Kermanshah city was selected for this research. Therefore, in this research, the concentrations of heavy metals such as Cd, Pb, Cr, Cu, Co, Mn, Zn, Ni, and As as metalloids in the scalp hair samples collected from the urban areas of Kermanshah city were determined and compared with the results of other studies around the world. This study was also performed to investigate the significant differences in metal concentration in hair between the age groups.

Materials and Methods

The study population

This research was performed in Kermanshah city, Iran, which is located in the west of Iran at 34° 18′ 51″ N and 47° 03′ 54″ E. Kermanshah metropolis is the capital, and also, the largest city of Kermanshah Province with a population of 1 093 833 in 2016 and an area of 93 389 956 m^2 (17). Kermanshah is located at the intersection of the three provinces of Kurdistan, Lorestan, and Ilam, as well as one country (Iraq). The climate of Kermanshah is characterized by four distinct seasons. The city's elevation is at an exposed location relative to westerly winds, which causes rainfall a bit high. It also has cold winters and there is usually precipitation in spring and fall. Snow cover is observed for at least two weeks in winter. The mean annual temperature in Kermanshah city is 15.7°C and average annual rainfall is 386.8 mm (18). Kermanshah is the most important city in the central region of western Iran, and is considered as the agricultural center of Iran, with more than 256 active industrial units in this city (17).

Hair collection and sample preparation

In the present research, human scalp hair samples were collected from 30 healthy inhabitants (aged 6 to 46 years) from barber shops of 6 municipality districts of Kermanshah city. Each participant also completed a questionnaire composed of information about the following variables: age, smoking, car possession, and hair dyeing. Four age classes were considered: (1) 6-20 years old, (2) 21-30 years old, (3) 31-40 years old, and 41-50 years old. One to three centimeters of recent grown hair was used from the nape of the neck because the hair sample from the neck is commonly less contaminated by exogenous material than hair on the top and front of the head. A stainless steel scissor was used to cut the hair samples. Each person was asked in the prepared questionnaire about his age, job, and smoking. The hair samples were preserved in plastic bags and placed at room temperature until chemical analysis. In order to prepare samples for analysis, the hair samples were cut into smaller pieces and washed based on the method suggested by the IAEA Advisory Group with acetone, three times with deionized water, and finally, with acetone to eliminate surface impurity and any adhesive contaminations present on the surface of the hair. Then, all washed samples were dried in oven at 50°C to constant weight (19). 0.1 g of the scalp hair was accurately weighed and transferred to digestion vessel. A mixture of 10 mL HNO_3 acid and 1 mL of H_2O_2 was added for digestion. After completion of digestion, the solutions were allowed to cool to room temperature. The volume of digest made up to 25 mL with deionized water. Finally, the concentrations of heavy metals and As in the hair were determined by ICP-OES (Inductively coupled plasma - optical emission spectrometry).

Statistics analysis

All statistical analysis was performed using SPSS program. The Pearson's correlation coefficient was applied to evaluate the relationships between the heavy metals in the hair samples. A principal components analysis (PCA) was also used to identify groups of metals.

Results

The descriptive statistics of heavy metals and Arsenic in the human hair in the urban areas of Kermanshah are summarized in Table 1. The concentrations of the elements in the human hair samples decreased in the order Fe > Zn> Cu > Pb> Cr > Mn > Ni> Co > Cd > As. The mean concentration of Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb, and As in the scalp hair samples was as follows: 33.53, 27.98, 203.18, 1.94, 18.44, 107.11, 119.21, 0.97, 60.27, and 0.34 µg/g, respectively. The coefficient of variation demonstrates that As has the highest CV while Zn has the least one. The highest value of CV was observed for As (66%), followed by Co, Cd, Mn, Cr, Pb, Cu, Ni, Fe and Zn, respectively. Arsenic indicated the highest CV among other elements in the hair samples, which reflects the variation in the concentration of As.

Table 1 indicates the comparative findings of the elements in human hair for the study area against the worldwide concentrations of the elements. The metals concentration in human hair in the present research was high compared to those reported in other worldwide studies, indicating environmental influence such as dust and air pollution on the biological samples.

The distribution of the elements in human hair was different by age groups (Figure 1), where the highest concentration of all metals were found in the age groups of 31-40 and 41-50 years except Fe, the maximum concentration of which was between 6-20 years. No differences were significant only for Mn between the samples taken from participants in the age group of 6-20 years and all other groups ($P < 0.01$).

Smoking influences the level of Cr, Ni, Cd, Pb, and As ($P < 0.001$) as well as Mn, Cu, and Zn ($P < 0.01$). No significant differences were found in case of Fe. Car possession have an impact on Cr ($P < 0.05$) only.

Data of Pearson's correlation coefficient of elements in scalp hair of people of Kermanshah city are presented in Table 2. A significant positive correlation ($P < 0.05$) was

Table 1. Statistics of the determined elements (µg/g) in hair samples and their comparison with the results of different countries

	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	As	Reference
Minimum	ND	9.01	150.89	0.45	11.90	ND	100	0.4	38.60	0.01	Present study
Maximum	46.40	49.40	231.52	4.15	27.30	134.40	147	1.90	98.10	1.89	Present study
Mean	33.53	27.98	203.18	1.94	18.44	107.11	119.21	0.97	60.27	0.34	Present study
SD	9.05	7.77	22.31	0.85	3.40	22.56	10.52	0.36	13.84	0.51	Present study
CV	27%	28%	11%	44%	18%	21%	9%	37%	23%	66%	Present study
Beijing	0.782	-	-	-	-	-	-	0.07	1.56	0.13	(5)
Poland	0.568	-	-	-	-	-	-	0.11	1.05	0.04	(9)
India	-	-	-	-	-	-	-	0.13	4.65	2.29	(8)
Balkan	-	2.4	-	-	1.75	13.7	166	0.26	-	-	(15)
Pakistan	2.61	1.69	-	-	-	-	154.2	2.13	14.62	-	(11)
Pakistan	3.3	1.93	-	-	-	-	226	0.38	15.97	-	(10)
Libya	3.93	1.73	-	-	-	-	190	0.53	24.95	-	(10)
France	0.20	-	-	-	-	-	-	0.01	0.41	0.05	(24)
Norway	-	0.36	-	-	-	76.5	190	0.04	-	-	(21)
Spain	-	-	-	-	0.04	12.5	161	0.03	0.27	-	(19)
Huainan city, China	1.56	-	31.13	-	-	14.96	166.54	-	6.41	1.07	(22)
Turkey	0.93	-	25.01	-	-	15.75	109.76	-	5.10	1.14	(23)
Shanghai China	-	-	-	-	-	11.42	121.20	-	1.64	-	(27)
Russia	-	-	-	-	0.413	-	-	0.03	1.05	0.05	(26)
Rome, Italy	0.99	0.35	19.0	0.67	1.49	22.1	150	0.23	7.11	0.09	(24)

ND: Non-detected.

Table 2. Correlation coefficient matrix of elements in the human scalp hair samples from Kermanshah

	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	As
Cr	1									
Mn	0.50**	1								
Fe	0.21	0.08	1							
Co	0.23	0.45**	-0.02	1						
Ni	0.61**	0.72**	0.38*	0.20	1					
Cu	0.77**	0.79**	0.19	0.25	0.75**	1				
Zn	0.60**	0.62**	0.05	0.15	0.55**	0.77**	1			
Cd	0.40*	0.48**	0.49**	0.09	0.53**	0.45**	0.32*	1		
Pb	0.46**	0.49**	0.52**	0.17	0.66**	0.56**	0.64**	0.54**	1	
As	0.77**	0.34*	-0.01	0.07	0.35*	0.58**	0.54**	0.31*	0.32*	1

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

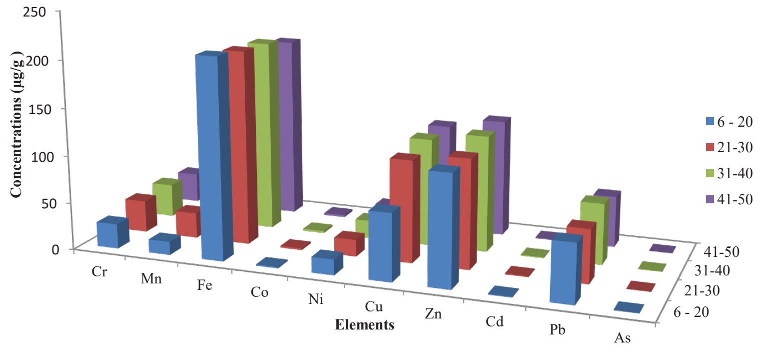

Figure 1. Distribution and average concentration (µg/g) of elements in hair samples by age.

found between Mn/Cr, Ni/Cr, Cu/Cr, Zn/Cr, Cd/Cr, Pb/Cr, As/Cr, Co/Mn, Ni/Mn, Cu/Mn, Zn/Mn, Cd/Mn, Pb/Mn, As/Mn, Fe/Ni, Fe/Cd, Fe/Pb, Ni/Cu, Ni/Zn, Ni/Pb, Ni/Cd, Ni/As, Cu/Zn, Cu/Cd, Cu/Pb, Zn/Pb, Zn/As, Cd/Pb, Cd/As, and Pb/As, indicating their possible common variations or sources in the scalp hair of the population. The correlation between Cr/Fe, Co/ Cr, Fe/Mn, Co/Fe, Cu/Fe, Zn/Fe, Fe/As, Co/Ni, Co/Cu, Co/Zn, Co/Cd, Co/Pb, and Co/As was not significant ($P < 0.05$).

Principal components analysis loadings for hair elements are summarized in Table 3. Two factors were extracted with a cumulative variance of 69.07% for the scalp hair samples. PC1 and PC2 explain 53.56% and 15.51% of the total variance, respectively. The first component was correlated with Fe, Ni, Zn, Cd, Pb, and As. The second component was underlined by a significant factor loading for Cr, Mn, Co, and Cu.

Discussion

Concentrations of elements

The high levels of metals in hair is probably associated with the different sources of contamination, which typically exist in urbanized centers (3). According to the CV results, dispersion of As in the hair samples was

Table 3. Total variance explained and matrix of principal components analysis for the elements in hair samples

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.36	53.56	53.56	5.36	53.56	53.56	3.56	35.63	35.63
2	1.551	15.51	69.07	1.55	15.51	69.07	3.34	33.44	69.07
3	0.93	9.35	78.43						
4	0.72	7.20	85.63						
5	0.49	4.88	90.51						
6	0.40	4.03	94.54						
7	0.30	2.96	97.50						
8	0.15	1.49	98.98						
9	0.08	0.84	99.83						
10	0.02	0.17	100.00						
	Component matrix			Rotated component matrix					
Metal	PC1	PC2		PC1	PC2				
Cr	0.76	0.50		0.21	0.88				
Mn	0.87	0.22		0.48	0.75				
Fe	0.43	-0.59		0.72	-0.13				
Co	0.38	0.29		0.08	0.47				
Ni	0.83	-0.26		0.78	0.38				
Cu	0.65	0.66		0.02	0.93				
Zn	0.82	-0.02		0.62	0.55				
Cd	0.75	-0.40		0.82	0.22				
Pb	0.82	-0.40		0.87	0.27				
As	0.81	0.01		0.58	0.56				

found higher than the other elements. The other nine metals varied lowly or moderately, indicating variations of elements distribution in the Kermanshah inhabitants' scalp hair. In comparison to standard levels of metals in the hair of various Chinese populations offered by the Trace Element Research Council of China (TERCC: Cu (Adult: 8-20, Children: 8-16); Pb (Adult and Children < 10); Zn (Adult: 120-210, Children: 90-170); Cd (Adult < 0.6 and Children < 0.5); Cr (Adult: 0.30-1.20, Children: 0.18-0.72); Mn (Adult: 0.8-2.8, Children: 0.7-2.0)), the concentrations of Cu, Pb, Cd, Cr, and Mn were higher and the concentration of Zn was lower.

Zn and Mn had the highest mean concentration in hair samples (Table 1). This could be due to the type of treatment given to hair, or due to feeding habits. Some metals such as Zn, Cr, Mn, and Cu are necessary nutrients for various physiological functions. These metals are also present in pharmaceutical products. This is because a wide variety of metals mostly transition elements are employed as complexes or salts to act as catalysts, thus, any pharmaceutical excipient whose synthesis involves the use of one or more element catalysts may contain residual metals in form of the original catalysts or as derivative. It may accumulate in human body when taken, which may add to this metal content in the body.

Comparison with other studies

The average Zn concentrations (119.21 ± 10.52 μg/g) were lower than those obtained in Balkan (15), Pakistan (11; 20), Norway (21), Spain (19), China (22), and Libya (20), but higher than those reported in Turkey (23). The findings showed that the concentration of Pb in the scalp hair was very high. The Pb concentrations in the present study ranged 38.60-98.10 μg/g with the mean value of 60.27, which is higher than that reported by Senofonte et al (24), Samanta et al (8), Chojnacka et al (9), Goullé et al (25), Shah et al (20), Gellein et al (21), González-Muñoz et al (19), Pasha et al (11), Benderli Cihan and Yıldırım (23), Skalny et al (26), Liang et al (5), Wang et al (27), and Sahoo et al (15). Among ten studied elements, Lead indicated relatively higher concentrations as compared with other studies around the world. The As concentrations in Kermanshah city indicated the mean value of 0.34 with a range of 0.01 to 1.89 μg/g. Compared to other countries such as France (mean value: 0.05; (25)), Russian population (mean value: 0.08; (26)), Beijing (mean value: 0.127; (5)), Rome, Italy (mean value: 0.09; (24)), As concentrations in Kermanshah were higher than those reported in these countries. The mean level of Cd (0.97 μg/g) in the Kermanshah inhabitants' hair samples was within the range of the world's mean concentration (0.4-1.0 μg/g) (28) and was higher than that reported in all of the compared countries except Pakistan (11). Based on Table 1, the concentrations of Cr, Mn, Fe, Ni, and Cu in the scalp hair samples of Kermanshah residents were relatively higher than those reported in most of the countries listed.

When comparing the elements content, the concentrations of the elements found in this study were clearly higher than those obtained from other studies. The elemental composition in hair is affected by various factors. Undoubtedly, one of them is nutrition. In the present research, the concentration of As was higher than the allowable values (0.08-0.25 mg As/kg hair) and higher than that reported in Beijing (0.127 μg/g) and Poland (0.044 μg/g) but lower than that in India (2.29 μg/g). However, it should be noted that different analytical and washing procedures were applied and since currently no standardized method for analysis of hair exists, the findings of different studies must be compared with prudence (7). The measured concentrations of elements compared with other data show that they are relatively higher that the levels reported in the literature.

Age groups

Therefore, the levels of elements such as Cu, Zn, Cr, Ni, Mn, Co, and Cd increase with age, which indicates the bioaccumulative properties of these elements. The levels of Pb and As do not show a clear trend with increasing age. The concentrations of some potentially toxic elements in human tissues usually increase with age (29). Consistent with the results of this study, Fang et al (22) found that concentrations of Cr, Fe, Zn, and As in hair also increase with age. Several studies have reported that the concentration of elements in human hair is related to sex and age, geographic changes, nutrition, and environmental factors.

Other factors (cigarette smoking, car possession)

The leaves of tobacco naturally concentrate and accumulate relatively high concentrations of metals such as Cd, Ni, Pb, Fe, Cu, hence, smoking tobacco is a main source of exposure to these elements for smokers (30). Consistent with the results of this study, other studies (31,32) reported that smokers commonly exhibited significantly higher metals body burdens than non-smokers. In the study of Varhan Oral (32), the average concentration of Pb (1.85 μg/g) in hair of smokers was 2.5 times higher than that of Pb (0.79 μg/g) in non-smokers hair. Mortada et al (33) compared concentration of Pb in hair of smokers and non-smokers aged 25-35 years in Egypt, and found that smokers have substantially higher Cd and Pb levels. Car possession has an impact on Cr ($P < 0.05$) only. Another factor is the effect of some diseases on the trace element content in hair (34) that must be evaluated.

Correlation analysis

Also, the correlation analysis demonstrated significant mutual relationships among the essential and non-essential metals (e.g. Cd and Pb with Fe, Cu, and Zn). This proposed that the toxic metals show risk to the essential metal homeostasis. Apparently positive relationship of the elements with the nutrients evidenced accumulation of the elements in the unhealthy persons (35).

Principal component analysis

To reduce the dimensionality of a set of data and to identify possible pollution sources of heavy metals in hair, PCA was used to group the variables into independent factors accounting for the maximum explainable variance of original data (36). The PCA were applied to identify the sources of the elements in hair. The first component was correlated with Fe, Ni, Zn, Cd, Pb, and As. These elements could have originated from a mixture of vehicle's exhaust and non-exhaust sources (brake and tire wear) (37). The second component was underlined by significant factor loading for Cr, Mn, Co, and Cu, which may be related to the diet (38). Pb had the highest contribution to PC1 and all the loadings had positive signs, indicating that each metal influences PC1 in the same way. Cu had the highest contribution to PC2. All the loadings corresponding to PC2 had also positive signs, indicating that all the metals interact in the same way.

Conclusion

Based on the element concentrations in the scalp hair of residents from urban areas, it can be concluded that the urban environment in Kermanshah has been influenced by heavy metals (As, Cd, Pb, Cr, Cu, Co, Mn, Zn, Fe, and Ni) and arsenic. Urban residents might be exposed to higher levels of elements. Elements such as Cu, Zn, Cr, Ni, Mn, Co, and Cd levels increase with age, indicating the bioaccumulative properties of these elements. The mean concentrations of the elements in smoker's hair were higher than those in non-smokers' hair. The findings from the present research indicate that hair is a simple, non-invasive, and cost-effective procedure that can provide preliminary data on the urban residents exposure to toxic elements. From multivariate analysis, PC1 is heavily weighted by Fe, Ni, Zn, Cd, Pb, and As, indicating that these elements may be derived from a mixture of vehicle's exhaust and non-exhaust sources (brake and tire wear). PC2 is heavily weighted by Cr, Mn, Co, and Cu, indicating that these elements may be related to diet. Further studies are recommended to assess the element concentrations in hair and to confirm the results obtained from this research.

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Ethical issues

Ethical issues (e.g., plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Competing interests

The authors declare that they have no conflict of interests.

Authors' contributions

All authors contributed and were involved in the problem suggestion, experiments design, data collection, and manuscript approval.

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