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LEAD AND CADMIUM CONTENT IN HUMAN HAIR IN CENTRAL POMERANIA (NORTHERN POLAND)

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Abstract

Samples of hair collected in 2004-2007 from 416 persons living in Central Pomerania were analyzed. The subjects donating hair represented a vast spectrum of age, from a ten-month-old child to a 75-year-old person. The subjects were selected randomly. Lead and cadmium were determined by atomic absorption spectrophotometry using an ASA-3 spectrometer. The average content of the metals in the hair samples was 3.20 μg g^{-1} (Pb) and 0.284 μg g^{-1} (Cd). The highest concentration of lead in human hair (about 3.88 μg g^{-1}) was determined for the age group 61-75 years, and that of cadmium (0.406 μg g^{-1}) – for the age group 26-50 years. The lowest concentrations of these metals in human hair (2.07 and 0.152 μg g^{-1}, respectively) were determined for the age group of 0-15 years. Most hair samples (50%) contained 2.01-4.00 μg g^{-1} Pb, while 45% of the samples contained 0.001--0.300 μg g^{-1} of cadmium. Studying the dependence of the content of lead and cadmium in hair on the gender of subjects, it was discovered that in all age groups males had more lead and cadmium (3.79 and 0.334 μg g^{-1}, respectively) than females (2.63 μg g^{-1} and 0.236 μg g^{-1}). This study has also demonstrated that the environment affects the content of the analyzed metals in hair. The average value of lead and cadmium concentrations for people living in the country were 2.39 μg g^{-1} for Pb and 0.214 μg g^{-1} for Cd, while for the people living in towns and cities, the respective values were 4.17 and 0.361 μg g^{-1}. The present study has demonstrated how nutrition affects lead and cadmium content in human hair. Among the subjects, 17% had been on some kind of a diet, predominatly easily digestible and light foods. The lowest content of these metals (on average, 2.08 μg g^{-1} Pb and 0.141 μg g^{-1} Cd) was found in hair of people on a diet, while the hiest levels (3.54 μg g^{-1} Pb and 0.315 μg g^{-1} Cd) were determined in people who did not limit consumption of meat and dairy products. Among the analyzed population, 241 persons suffered from chronic disease. The average content of lead and cadmium in hair of healthy subjects was 3.05 μg g^{-1} Pb and 0.257 μg g^{-1} Cd, but in patients suffering from arthrosclerosis, allergy and hyperplasia prostate the levels of lead and cadmium in hair reached the upper values of the-

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se limits. Hair of the patients who suffered from cardiovascular disease showed deificiency of these metals (on average, 1.73 μg g^{-1} Pb and 0.182 μg g^{-1} Cd).

Key words: lead, cadmium, hair, personal features, environment, nourishment, chronic diseases.

ZAWARTOŚĆ OŁOWIU I KADMU WE WŁOSACH LUDZI Z POMORZA ŚRODKOWEGO (PÓŁNOCNA POLSKA)

Abstrakt

W latach 2004-2007 dokonano analizy włosów 416 osób pochodzących z Pomorza Środkowego, w szerokim zakresie wiekowym, od kilkumiesięcznych dzieci do osób w wieku 75 lat. W badanych włosach oznaczano zawartość kadmu i ołowiu metodą spektrofotometrycznej absorpcji atomowej. Średnia ich zawartość wyniosła odpowiednio 3,20 μg g^{-1} (Pb) i 0,284 μg g^{-1} (Cd). Najwyższe stężenie ołowiu (średnio 3,88 μg g^{-1}) we włosach stwierdzono w grupie wiekowej 61-75 lat, a kadmu (0,406 μg g^{-1}) w grupie 26-50 lat. Natomiast najmniejszą koncentrację tych metali (odpowiednio 2,07 i 0,152 μg g^{-1}) odnotowano wśród dzieci 0-15 lat. Włosy większości badanych osób zawierały od 2,01 do 4,00 μg g^{-1} Pb i od 0,001 do 0,300 μg g^{-1} Cd. Badając zależność zawartości metali we włosach od płci, stwierdzono, że we wszystkich grupach wiekowych u płci męskiej stwierdzono więcej ołowiu i kadmu (3,79 i 0,334 μg g^{-1}) niż u płci żeńskiej (2,63 i 0,236 μg g^{-1}). Na zawartość analizowanych metali we włosach istotny wpływ wywiera środowisko. U osób mieszkających na wsi stwierdzono we włosach znacznie mniej tych metali (średnio: 2,39 μg g^{-1} Pb i 0,214 μg g^{-1} Cd) niż u osób mieszkających w mieście (odpowiednio 4,17 i 0,361 μg g^{-1}). Znaczący wpływ na koncentrację ołowiu i kadmu we włosach wywiera rodzaj spożywanych pokarmów. Stwierdzono, że osoby, które nie spożywały mięsa i wyrobów mięsnych oraz mleka i jego produktów miały we włosach najmniej tych metali (średnio 2,08 Pb i 0,141 μg g^{-1} Cd), a u osób, które nie unikały tych produktów, włosy zawierały najwięcej ołowiu i kadmu (3,54 i 0,315 μg g^{-1}). Wykazano, że może istnieć związek między niektórymi przewlekłymi chorobami u badanych osób a poziomem wymienionych pierwiastków w ich włosach. Przeciętna zawartość ołowiu i kadmu we włosach ludzi zdrowych wynosiła odpowiednio 3,05 i 0,257 μg g^{-1}. U alergików i osób chorujących na rozrost gruczołu krokowego lub niedokrwistość stwierdzono we włosach więcej tych metali niż u ludzi zdrowych, a u osób chorujących na nadciśnienie tętnicze znacznie mniej.

Słowa kluczowe: ołów, kadm, włosy, cechy osobiste, środowisko, odżywianie, choroby przewlekłe.

INTRODUCTION

Heavy metal pollution has become a serious health concern in recent years. Continuous exposure to low levels of heavy metals may result in bioaccumulation and health deterioration in humans. Toxic heavy metals of greatest concern are cadmium, lead and mercury. The exposure to these metals is a continuous daily process, as they can be found at the place of work, in potable water, in food and in the air (GOYER 1996). Moreover, metals can enter an organism via different routes, i.e. they are transferred from the air, water, food or pharmaceuticals applied through skin and the respiratory tract. Afterwards, they are transported and distributed through blood into organs (i.e. liver, kidney) and removed from the organism through the following excretory pathways: sweat, hair, urine and faeces (APOSTOLI 2002, LEE et al. 2000). Measuring levels of metals in human bodies is usually done by analyzing human fluids. Fluids, such as blood and urine, are often considered the best specimens for evaluation of undue exposure, but the results reflect a transient situation (WILHELM et al. 2002). Other materials such as scalp hair clippings can be used as biomonitors because human hair is an excretory system for trace metals and can act as an accumulating tissue, therefore the metal content in hair can reflect the body status over a long period, including exposure to metals in time (ALMEIDA et al. 1999, APOSTOLI 2002, D'HAVÉ et al. 2006). Besides, concentration of metals in human hair may be to 10-fold higher than the amount found in blood or urine (MORTADA et al. 2002, SANNA et al. 2003). The high affinity of hair to metals is mainly due to the presence of cysteine, which makes up approximately 14% of human hair (MORTON et al. 2000).

Hair analysis is a promising tool for routine clinical screening and diagnosis of heavy metal exposure and essential trace element states in the human body (CONTIERO, FOLIN 1994, CAROLI et al. 1998, STRZELCZYK et al. 2001). Deficiency or excess of essential elements such as Ca, Zn, Cu and Fe in hair have been correlated with diseases and nutritional status (MAN et al. 1996, BOCCA et al. 2006). It has been shown that there is a relationship of hair assays with some imbalance of various metals in patients (MIEKELEY et al. 2001, FORTE et al. 2005). The trace element profiles in hair of cancer patients were also found to be different from those of healthy people (KOŁMOGOROW et al. 2000). They are also linked to neurological disease (BOCCA et al. 2006).

The impact of environmental exposure has been discussed in numerous publications for a long time, especially with respect to lead and cadmium (BENCO 1995, KUBOVA' et al. 1997, NOWAK, CHMIELNICKA 2000). Data on concentrations of these metals in hair are found in the following papers from various countries: SUKUMURA, SUBRAMANIAN 1992, CONTIERO, FOLIN 1994, KOZIELEC, DRYBAŃSKA-KALITA 1994, ZABOROWSKA, WIERCIŃSKI 1997, HAĆ et al. 1998, NOWAK, CHMIELNICKA 2000, CHOJNACKA et al. 2006. Cadmium and lead consumed in moderate amounts over many years can become detrimental to human health.

The aim of this work has been to assess the influence of personal features, environment, nourishment and health state on lead and cadmium content in hair of a population living in Central Pomerania.

MATERIAL AND METHODS

In 2004-2007, a study was conducted on hair samples from 416 individuals living in Central Pomerania. These people represented a wide age spectrum, I,e, from a 10-month-old infant to a 75-year-old elderly person. They were selected for the study in a random manner. An interview was conducted using a chart prepared in advance, including personal data, the place of residence, profession (for children – the profession of their parents), diet, health state and hair colour. Children were interviewed in the presence of their parents. All respondents were divided into four age groups: children (up to 15 years of age), young people (aged 16-25 years), adults (26-50 years) and elderly people (51-75 years of age).

Analyses were conducted on hair not subjected previously to hairdressing procedures. Hair samples were cut at the scalp at 6 different locations on the head. Hair sections of 3 cm from the scalp were analyzed chemically. The total amount of hair collected from each individual and then analyzed ranged from 0.3 to 0.5 g. Hair samples were rinsed with acetone followed by triple rinsing with water and then a repeated rinsing with acetone. Washed hair was dried to constant weight at 105°C. Dried samples were weighed and then mineralized using a mixture of concentrated nitric and perchloric acids (mixed at a ratio of 5:1). The content of lead and cadmium in the solution was determined by atomic absorption spectrometry with an ASA-3 spectrometer equipped with an attachment consisting of an EA3 electromagnetic atomizer and an automatic sample injector port. For all measurements identical analytical parameters were applied, i.e. wavelength of 324.8 nm (Pb) and 228.8 nm (Cd), lamp current 6 mA and a 10 mm slit. The results were read from the plotted analytical curve and expressed in $\mu g\ g^{-1}$ hair dry matter. The precision and repeatability of the method were verified (using 10 uniform hair samples) and the recovery of cadmium and lead was analyzed (by adding a known amount of the standard solution to 10 uniform hair samples and at the same time investigating Cd and Pb contents in these samples with no standard added). The correlation coefficient of the analytical curve was 0.992 (Cd) and 0.997 (Pb). In turn, the coefficient of variation for repeatability of the applied method was 6.41 and 3.52%, respectively, mean recovery was 99.0 and 99.5%, while the mean error of method was 7.8 and 4.2%, respectively.

The results were developed statistically using Student's *t*-test and values of correlation coefficients.

RESULTS AND DISCUSSION

It results from data reported in literature that the level of minerals in hair is many times higher than in blood or urea (MAUGH 1978, ELTAYEB, VAN GRIEKEN 1990, RADOMSKA et al. 1993, WILHELM et al. 2002, BOCCA et al. 2006). Thus, analysis of hair samples considerably facilitates the entire analytical procedure in terms of the detectable content of these substances in the organism and reduces analytical errors. Another very important advantage of this method is its non-invasiveness. Chemically, hair is composed of protein rich in cystein, which, owing to hydrogensulfide groups, has the ability to bind metal ions, therefore hair analysis relatively precisely determines content of metals in the organism (CONTIERO, FOLIN 1994, BORZĘCKA et al. 1999, ZABOROWSKA, WIERCIŃSKI 1997, HARKINS, SUSTEN 2003). Also melanin binds certain metals (BILIŃSKA 2001).

In 2004-2007, hair samples from 210 females and 206 males were analyzed in terms of their lead and cadmium contents.

Table 1 contains mean contents of analyzed metals, the range of data, standard deviations, coefficients of variation and numbers of individuals in each age group as well as percentages in the total population. A considerable range of fluctuations was observed in all age groups in terms of the content of these metals in hair. In turn, small values were recorded for standard deviation, which reflected average variation of results. The least numerous groups comprised children, who accounted for approx. 19% of the analyzed population, whereas the other age groups were comparable in size (over 25%).

Table 1

The content of lead and cadmium (μg g^{-1}) in hair of people from Central Pomerania

Age groups	n	U%	Pb				Cd			
			x^*	x_{min}	x_{max}	SD	x^*	x_{min}	x_{max}	SD
0 - 15	80	19.2	2.07	0.10	7.90	0.18	0.152	0.027	0.678	0.024
16 - 25	106	25.5	2.84	0.60	9.74	0.24	0.288	0.033	0.769	0.026
26 - 50	109	26.2	3.71	1.20	9.39	0.29	0.406	0.075	0.773	0.035
61 -75	121	29.1	3.88	0.62	8.51	0.35	0.260	0.038	0.720	0.022
0 - 75	416	100.0	3.20	0.10	9.74	0.28	0.284	0.027	0.773	0.025

n – number of subjects, U% – share, x^* – average value

The results showed that the mean concentration of lead and cadmium in hair of the population of inhabitants of Central Pomerania, aged 0-75 years, was 3.20+0.28 and 0.284±0.025 μg g^{-1}, respectively. In order to verify whether this level of analyzed metals is safe it would be necessary to compare it with analogous concentrations in hair of people living in areas not exposed to the action of these metals, since metal concentrations in the organism, including hair, depend on the geographic zone, or even the region of a country. Moreover, detected levels of heavy metals change with the improvement of testing methods, facilitating a more precise determination of admissible concentrations. Thus, it is advisable to compare recorded values with literature data concerning individuals not exposed to the action of lead and cadmium compounds. Table 2 presents mean concentrations of these metals in hair of people not living in urban areas and not exposed to metals in their workplace. The values for Pb ranged from 0.3 to 10.8 μg g^{-1}, while for Cd they varied from 0.028 to 0.83 μg g^{-1}; however, in 11 out of the 13 cited studies, this range was much narrower (1.0-7.0 μg g^{-1} and 0.10-0.60 μg g^{-1},

Table 2

Reference data on lead and cadmium content (μg g^{-1}) in human hair

Pb		Cd		References
*X**	range	*X**	range	
2.85 - 11.64	-	0.18 - 0.33	-	Garry, Gordon 1985
4.34	1.2 - 11.4			Zaborowska et. al. 1989
1.54 - 2.60	0.20 - 8.7	0.23 - 0.31	0.01 - 1.30	Kozielec, Drybańska-Kolita 1994
3 - 4	1.7 - 6	0.23 - 0.27	0.1 - 0.55	Wasiak et. al. 1996
1.84 - 3.31	0.03 - 3.09	0.26 - 0.37	0.02 - 1.34	Zaborowska, Wierciński 1997
4.47	-	0.245	-	Ren et. al. 1997
0.299 - 2.81	-	0.028 - 0.150	-	Caroli et. al. 1998
		0.35	-	Hać et. al. 1998
3.7 - 5.8	-	0.5 - 0.9	-	Lekouch et. al. 1999
4.8	-	0.55	-	Nowak, Chmielnicka 2000
6.82	2.7 - 12.2	0.35	0.08 - 0.82	Mortada et. al. 2002
1.05 - 4.99	-	0.114 - 0.610	-	Chojnacka et. al. 2005
2.6	-	0.83	-	D'Have et. al. 2006
10.8	-	0.5	-	Sukumar, Subramanian 2007

respectively). Content of lead and cadmium in hair of the examined inhabitants of Central Pomerania fell within this narrower range and it was almost two-fold smaller than in the area of the city of Katowice (Nowak, Chmielnicka 2000). Similar results concerning lead were also reported by Borzęcka et al. (1999) and Sanna et al. (2003). In turn, in hair of individuals exposed to these metals in their workplace, the recorded values were much higher than reference values (Zaborowska et al. 1989, Wasiak et al. 1996).

In the examined population, lead content in hair was increasing with age (Table 1). Figures 1-4 present changes in concentrations of this metal depending on age in individual groups. The highest level of lead was found in hair of individuals aged approx. 60 years, fluctuating around 4.5 μg g^{-1} (Figure 4). The lowest lead content was recorded in hair of children, while the highest one – in hair of elderly people (Table 1). This difference is statistically non-significant (p = 0.05). In the group of children, a decreasing

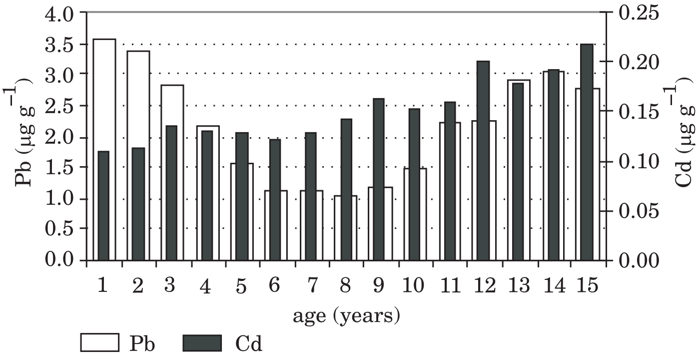

Fig. 1. Mean values of lead and cadmium (µg g^{-1}) in children's hair (1-15 years) from Central Pomerania

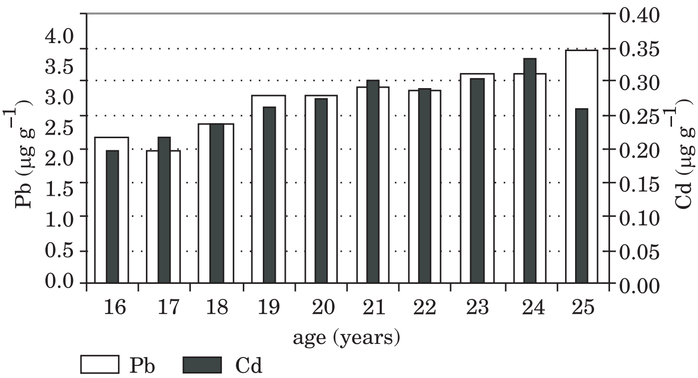

Fig. 2. Mean values of lead and cadmium (µg g^{-1}) in human hair (16-25 years) from Central Pomerania

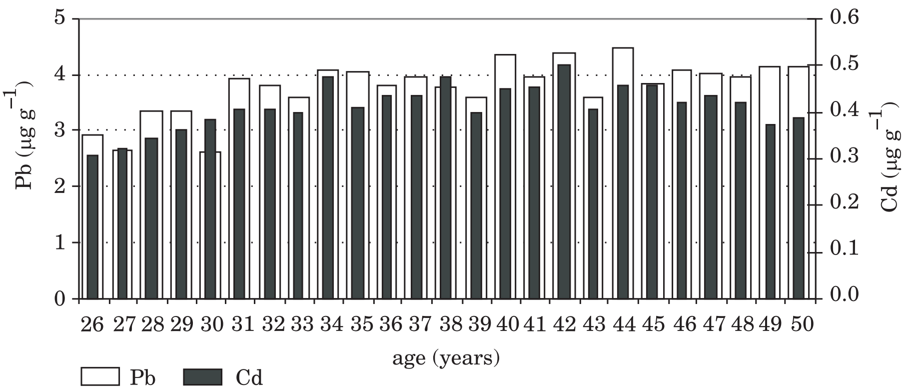

Fig. 3. Mean values of lead and cadmium (µg g^{-1}) in human hair (26-50 years) from Central Pomerania

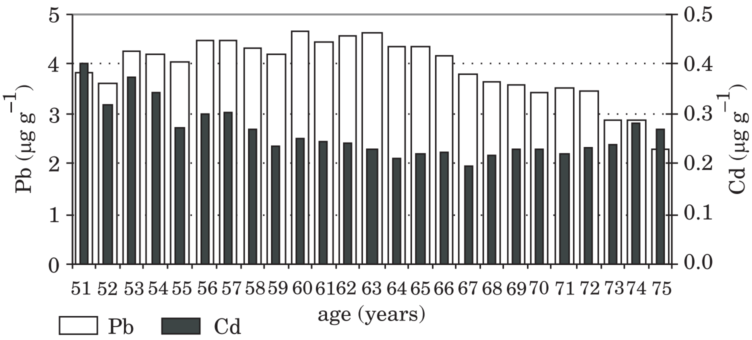

Fig. 4. Mean values of lead and cadmium (µg g^{-1}) in human hair (51-75 years) from Central Pomerania

tendency was observed for lead content in hair with age, but it was only up to 8 years of age (Figure 1). After that time, the content of this metal in hair increased from 1.04 to 3.03 µg g^{-1} at the age of 14 years. The dependence of lead level in hair on the age of children was confirmed by significant correlation coefficients with very high values (at the age of 0-8 years r = 0.89, 9-15 years r = 0.81, p = 0.05). Similar changes among children (aged from 5 to 18 years) were observed by Kozielec and Drybańska-Kalita (1994), with the minimum level of this element being recorded at the age of 7 years. When examining Moroccan children aged 6 to 14 years, Lekouch et al. (1999) found that the lowest amount of lead in hair was recorded for children aged 10 years. In turn, Ashraf et al. (1995) reported that the mean content of this element in hair of Pakistani children aged 11-15 years was higher than in children aged 6-10 years. In turn, it results from a study by Chojnacka et al. (2006) that Pb content in hair of examined children decreased after 7 years.

Lead content in hair was increasing consistently in successive age groups. In age groups of 16-25 years (Figure 2) and 26-50 years (Figure 3), a trend was observed for lead content in hair to increase with age. In the group of young people (16-25 years) the content of this metal increased from the mean value of 2.17 µg g^{-1} to 3.45 µg g^{-1}, while among adults (26-50 years), it grew from 2.90 to approx. 4.15 µg g^{-1}. In these two age groups, the dependence of lead concentration in hair and the age of individuals was characterized by correlation coefficients of 0.86 and 0.72, respectively (p = 0.05). It needs to be stressed that among young people up to 9 years the content of this metal increased by 59%, while among adults up to 24 years it was by 43%. Thus, statistically speaking in young people lead content increased by approx. 0.14 µg g^{-1} annually, while in the case of adultsit grew by approx. 0.05 µg g^{-1}. In elderly people (aged 51-75 years) an upward trend was also observed for lead content in hair to increase with age, but it was only to the age of 60-64 years (on average, from 3.82 µg g^{-1} at the age of 51 years to 4.65 μg g^{-1} at 60 years, Figure 4). Afterwards, Pb content in hair was decreasing consistently with age, to drop to the value of 2.30 μg g^{-1} at the age of 75 years.

When investigating the population of people aged from 11 to 100 years, Garry and Gordon (1985) also observed that the maximum lead content in hair is found at the age of 50-60 years and next it consistently decreases with age. A similar dependence was reported by Ashraf et al. (1995), but only among women. In contrast, when analyzing hair samples of individuals aged from 7 to 55 years, Chojnacka et al. (2006) reported the highest lead concentration in hair of children, which decreased consistently with age until approx. 40 years, and next it increased again. In turn, Sukumar and Sabramanian (2007), when examining Indian males aged 16-75 years, recorded the highest concentration of this metal in hair of males aged 31-45 years (8.6 μg g^{-1}). The differences are probably caused by changes in metabolism which occur with age and by the fact that the examined individuals lived in different regions.

The mean content of cadmium in hair of the analyzed individuals (0.284 μg g^{-1}) was comparable to that observed by Garry and Gardon (1985) and Wasiak et al. (1996). It fell within the range of normal concentrations of this element in hair, i.e. below 1.0 μg g^{-1} (Chojnacka et al. 2005). An almost two-fold smaller concentration of cadmium in comparison to that of the examined individuals living in Central Pomerania was reported by Chojnacka et al. (2006) in hair of inhabitants in the city of Wrocław. In turn, inhabitants of Katowice had two-fold higher concentrations of this metal in their hair (Nowak, Chmielnicka 2000), while hair of inhabitants of New Delhi had almost three times as much cadmium (Sukumar, Subramanian 2007). A ten-fold or even one hundred-fold higher content of this metal was recorded in hair of individuals exposed to cadmium in their workplace (Wasiak et al. 1996). The concentration of this metal in hair changed with age of the discussed group of individuals. Analogously to lead, the lowest content of cadmium was found in hair of children, while the highest – in hair of adults (Table 2). The difference between these levels was statistically significant (p = 0.05). As shown in Figure 1, Cd content in hair of children (0-15 years) increased consistently with age, from 0.110 to 0.218 μg g^{-1}. This dependence was characterized by the correlation coefficient of 0.73 (n = 80, p = 0.05). Also in hair of young people (16-25 years) the content of this metal increased with age, reaching the highest mean of 0.334 μg g^{-1} in individuals aged 24 years (Figure 2), where this dependence was characterized by a high value of correlation coefficient of 0.86 (n = 106, p = 0.05). The estimated statistical annual increase of cadmium level in hair of children was 0.007 μg g^{-1}, while in hair of young people it was almost twice as high, i.e. 0.017 μg g^{-1}. The content of this metal in hair of adults (26-50 the lowest in years) also increased with age, but only to the age of approx. 42 years (Figure 3), when the mean cadmium content reached the highest value of 0.500 μg g^{-1}. The difference between this value and the mean concentration of this metal at the age of 26 years (0.307 μg g^{-1}) was statistically significant (p = 0.005). The observed increase of Cd content in hair in that age group was characterized by a correlation coefficient of 0.79 (n = 109, p = 0.05). After 42 years of age, the content of cadmium was found to decrease to the mean content of 0.389 μg g^{-1} at the age of 50 years. A further decrease in cadmium content in hair was observed among elderly people (51-75 years) from the mean value of 0.402 μg g^{-1} at the age of 51 years to 0.230 μg g^{-1} at the age of 70-75 years (Figure 4). This dependence was characterized by a correlation coefficient of 0.70 (n = 121, p = 0.05). The estimated statistical loss of cadmium was on average 0.012 μg g^{-1} within one year.

Similar age-related changes in the concentration of cadmium in hair were observed by SUKUMAR and SUBRAMANIAN (2007). In turn, CHOJNACKA et al. (2006) did not report significant changes with age. The highest concentrations of cadmium were found among individuals aged 20 years.

In the investigated population, in majority of the subjects (209 individuals, 51% of the analyzed population) the content of lead in hair ranged from 2.01 to 4.00 μg g^{-1} Pb (Table 3). In individual age groups, this distribution was as follows. Among children, 38 individuals (48%) had Pb content in their hair of 1.0-3.00 μg g^{-1}, while for 24 individuals (30%) it was below 1.01 μg g^{-1}. In the age group of young people (aged 16-25 years), the most numerous group of individuals (33%) had from 2.01 to 3.00 μg g^{-1} lead in their hair. The data found in Table 2 shows that the highest number of individuals among adults and elderly people (33 and 35%, respectively) had from 3.01 to 4.00 μg g^{-1} Pb in their hair. However, we need to remember that for the second in size group of adults (23%) the value ranged from 2.01 to 3.00 μg g^{-1}, while among elderly people, i.e. a group comprising 25% population, the content ranged from 4.01 to 5.00 μg g^{-1}.

Table 3

Number of persons in age groups with lead content in hair (μg g^{-1}) according to range brackets. The per cent share to the whole population given in parentheses

Age groups	Number of persons with specific lead concentration in hair						
	< 1.01	1.01-2.00	2.01-3.00	3.01-4.00	4.01-5.00	5.01-6.00	> 6.00
0 - 15	24 (30)	18 (23)	20 (25)	13 (17)	0 (0)	2 (2)	3 (3)
16 - 25	6 (6)	27 (25)	35 (33)	20 (19)	9 (8)	3 (3)	6 (6)
26 - 50	0 (0)	9 (8)	25 (23)	35 (33)	19 (17)	14 (13)	7 (6)
51 - 75	1 (1)	6 (5)	18 (15)	43 (35)	30 (25)	15 (12)	8 (7)
0 - 75	31 (7)	60 (14)	98 (23)	111 (28)	58 (14)	34 (8)	24 (6)

With respect to cadmium, 49% of the entire population (201 individuals) had from 0.101 to 0.300 μg g^{-1} Cd in their hair (Table 4). In turn, for most

Table 4

Number of persons in age groups with cadmium content in hair (μg g^{-1}) according to range brackets. The per cent share to the whole population given in parentheses

Age groups	Number of persons with specific cadmium concentration in hair					
	< 0.101	0.001-0.200	0.201-0.300	0.301-0.400	0.401-0.500	> 0.500
0 - 15	29 (36)	36 (46)	10 (12)	2 (2)	0 (0)	3 (4)
16 - 25	6 (6)	26 (25)	36 (34)	19 (18)	10 (9)	9 (8)
26 - 50	2 (2)	3 (3)	17 (15)	33 (30)	28 (26)	26 (24)
51 - 75	10 (8)	28 (23)	45 (37)	20 (17)	13 (11)	5 (4)
0 - 75	47 (11)	93 (23)	108 (26)	74 (18)	51 (10)	43 (10)

children (82%) the level was below 0.200 μg g^{-1} cadmium. Among young people and elderly individuals the most numerous group (34 and 37%, respectively) comprised those with cadmium levels in their hair ranging from 0.201 to 0.300 μg g^{-1} Cd. In turn, 80% adult population had more than 0.300 μg g^{-1} of this element in their hair.

The fact that the level of both analyzed metals in hair of individuals living in Central Pomerania was observed to increase with age can most probably be attributed to environmental factors. Regression analysis showed significant correlation between content of lead and cadmium, characterized by a high correlation coefficient (r = 0.52, p = 0.05), and the regression equation $y = 0.065x + 0.079$. This dependence confirms the above conclusion and suggests that both metals probably come from the same source.

Table 5 presents lead contents in hair depending on gender. The investigations showed the effect of sex on Pb content in hair of the analyzed popu-

Table 5

Dependence of lead content (μg g^{-1}) in analyzed hair samples, in age groups, on gender

Range of content	Number of persons in individual age groups									
	female					male				
	0-15	16-25	26-50	51-75	0-75	0-15	16-25	26-50	51-75	0-75
< 1.00	13	4	0	1	18	9	0	0	0	9
1.00 - 5.00	24	50	54	61	189	29	43	35	37	144
> 5.0	0	1	1	2	4	5	8	19	20	52
Total	37	55	55	64	211	43	51	54	57	205
x^*	1.47	2.21	2.94	3.39	2.63	2.59	3.51	4.34	4.44	3.79
x_{min}	0.10	0.58	1.19	0.63	0.10	0.49	1.01	1.67	1.49	0.49
x_{max}	3.42	6.92	5.12	7.24	7.24	7.91	9.73	6.72	8.51	9.73
SD	0.15	0.24	0.25	0.30	0.26	0.22	0.41	0.38	0.38	0.39
$V\%$	10.2	10.9	8.5	8.8	9.9	8.5	9.5	8.8	8.6	10.3

x^* – average value, SD – standard deviation, $V\%$ – coefficient of changeability lation. The mean content of this metal in hair of female patients was by 44% lower than in hair of males. The difference between these values was statistically significant (p = 0.05). The biggest differences were observed between females and males in the group aged 26-50 years (on average by 1.40 μg g^{-1}). The differences recorded between concentrations of this element depending on gender were confirmed by the data published by other researchers (Garry and Gordon 1985, Chojnacka et al. 2006). Although Ashraf et al. (1995) found a similar dependence only among children aged up to 10 years, in those over 10 years they observed higher lead concentrations in hair of females than males. Also Sukumar and Subramanian (1996) reported higher concentrations of this metal in hair of females.

In each age group, over 90% females had 1.0-5.0 μg g^{-1} lead in their hair. For a considerable percentage of girls (35%), the content of this element was below 1.0 μg g^{-1}. In turn, among boys, only 21% had less than 1.0 μg g^{-1} Pb in their hair, while for most, as in the other age groups, its content ranged from 1.0 to 5.0 μg g^{-1}. However, results contained in Table 5 indicate that with age the proportion of males with the content of this metal in hair of more than 5.0 μg g^{-1} Pb is increasing.

Also in the case of cadmium, its content in hair of females was lower than in hair of males (Table 6). However, the difference between these values was not statistically significant (p = 0.05). It was only in the group of adults that the difference was on average 0.169 μg g^{-1} and as suchy was statistically significant. Also Garry and Gordon (1985), Reeves et al. (2001) and Chojnacka et al. (2006) reported higher content of this metal in hair of females than males. The smallest difference in cadmium content in hair was observed between girls and boys (0.035 μg g^{-1}) and it may be assumed

Table 6

Dependence of cadmium content (μg g^{-1}) in analyzed hair samples, in age groups, on gender

Range of content	Number of persons in individual age groups									
	female					male				
	0-15	16-25	26-50	51-75	0-75	0-15	16-25	26-50	51-75	0-75
< 1.00	9	5	2	5	21	13	0	0	1	14
1.00 - 5.00	28	47	45	56	176	27	36	14	41	118
> 5.0	0	3	8	3	14	3	15	40	15	73
Total	37	55	55	64	211	43	51	54	57	205
x^*	0.133	0.247	0.322	0.213	0.236	0.168	0.333	0.491	0.313	0.334
x_{min}	0.058	0.035	0.074	0.040	0.035	0.021	0.010	0.151	0.060	0.010
x_{max}	0.280	0.578	0.641	0.458	0.641	0.675	0.730	0.772	0.722	0.772
SD	0.014	0.023	0.030	0.024	0.024	0.020	0.034	0.042	0.032	0.035
$V\%$	10.5	9.3	9.3	11.3	10.2	11.9	10.2	8.5	10.2	10.5

x^* – average value, SD – standard deviation, V% – coefficient of changeability that in children the accumulation of this metal in hair is not sex-dependent. A vast majority of examined individuals, both females and males, had 0.10--0.40 μg g^{-1} cadmium in their hair, whereas in the age group of 26-50 years only 26% males had the same range of values, while 74% males had over 0.40 μg g^{-1} Cd in their hair.

When investigating the effect of lead and cadmium content in hair of the examined population, statistically significant differences were recorded only in the age group of 0-15 years. The lowest amounts of lead were detected in hair of children with the height of 101-120 cm, while the highest amounts were found in hair of children below 90 cm and over 140 cm tall (Figure 5). As for cadmium, its lowest amount was reported in hair of children less than 70 cm tall, while the highest for those of 161-170 cm in height. The difference in Pb and Cd content in hair observed between children with the lowest and highest amounts of these metals was approx. 1.9 μg g^{-1} and 0.19 μg g^{-1}, respectively. Among 80 examined children, the most numerous group comprised those betwee 131-140 cm tall (13 individuals), who made up 16.2% all children, characterized by the mean Pb content of 2.18 μg g^{-1} and mean Cd content of 0.161 μg g^{-1}. In turn, in the other analyzed age groups no correlation was found between content of lead and cadmium in hair and the height of examined individuals.

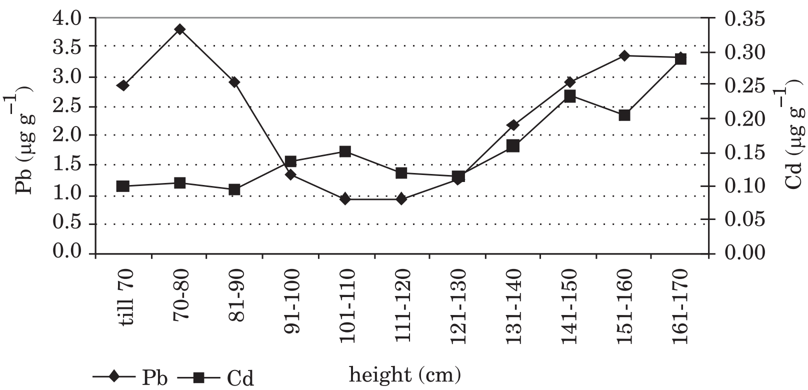

Fig. 5. Content of lead and cadmium (μg g^{-1}) in hair of children (1-15 years) depending on their height

In the examined individuals aged from 16 to 75 years, analogously to height, no effect of weight on content of lead and cadmium in hair was observed. A similar dependence for weight as that for height was found only in children. Children who weighed 36-40 kg had the lowest lead levels in hair, while in children of less than 15 kg and more than 55 kg it was on average more than 3.5 μg g^{-1} (Figure 6). The most numerous group (25 individuals) comprised children of 46-55 kg of weight, with a mean of 2.33 μg g^{-1} Pb and 0.188 μg g^{-1} Cd in their hair.

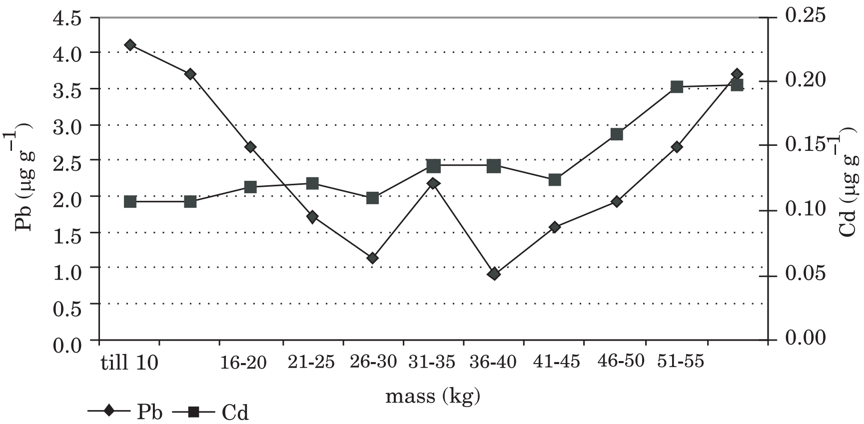

Fig. 6. Content of lead and cadmium (µg g^{-1}) in hair of children (1-15 years) depending on their weigth

When determining for each individual the obesity index (BMI) the effect of obesity on cadmium level in hair was observed, while no such correlation was recorded for lead. In all age groups, irrespective of the sex of individuals, an increase in cadmium content in hair was found with an increase in the degree of obesity (Table 7). For approx. 80% individuals in all age groups normal weight or overweight without obesity was recorded. Only in the age group of 51-75 years there were fewer such people (almost 70%), while as many as 28% individuals were classified as obese. The smallest differences in cadmium content in hair between individuals with the highest and the lowest obesity indexes were found between children, whereas the biggest differences were recorded between adults (26-50 years). Results showed that when penetrating the organism cadmium is accumulated in the adipose tissue to a much higher extent than lead.

Metal contents in different organs and tissues, including hair, are affected by several factors, such as e.g. content of these elements in the soil, drinking water and foodstuffs. As far as foodstuffs are concerned, the everyday diet is essential in this respect. Content of metals in foodstuffs and individual diet determine the supply of these elements in everyday diet. Most metals, consumed with food, are absorbed mainly in the small intestine. All chronic diseases of the alimentary tract reduce or even prevent its uptake. In turn, all permanent stressful situations also reduce the ability of the organism to absorb metals (RADOMSKA et al. 1991).

Thus, the adopted diet has a significant effect on content of lead and cadmium in hair, i.e. the organism. This pertains also to other metals (KAŁUŻA et al. 2001). When conducting research in this area, all individuals were divided into four groups: individuals who abstained from both meat and dairy products, individuals who consumed both these types of products, the group

Table 7

Influence of obesity on content of lead and cadmium in hair of the subjects divided according to gender and age
Number of persons given in parentheses

Metals	BMI	0 – 15 years			16 – 25 years			26 – 50 years			51 – 75 years		
		F	M	total	F	M	total	F	M	total	F	M	total
Pb	< 18.4	-	2.94 (1)	2.94 (1)	2.13 (1)	2.75 (3)	2.59 (4)	3.06 (4)	4.83 (2)	3.67 (6)	3.86 (1)	4.77 (2)	4.47 (3)
	18.5-24.9	1.10(17)	2.82(17)	1.96(34)	2.11(26)	3.81(20)	2.85(46)	3.14(28)	4.77(21)	3.84(49)	3.29(22)	4.44(21)	3.85(43)
	25.0-29.9	2.31(13)	2.84(17)	2.61(30)	2.60(18)	3.40(17)	2.99(35)	2.80(17)	4.22(22)	3.61(39)	3.70(23)	4.29(18)	3.96(41)
	30.0-34.9	0.65 (6)	1.49 (8)	1.89(14)	1.89 (8)	3.44 (5)	2.54(13)	2.49 (4)	3.73 (5)	3.18 (9)	3.08(12)	4.26(12)	3.67(24)
	35.0-39.9	2.06 (1)	-	2.06 (1)	1.41 (2)	3.57 (4)	2.78 (6)	2.65 (1)	4.70 (4)	4.29 (5)	3.41 (4)	5.84 (2)	4.22 (6)
	> 39.9	-	-	-	-	2.5 (2)	2.85 (2)	-	3.48 (1)	3.48 (1)	2.63 (2)	4.55 (2)	3.59 (4)
Cd	< 18.4	-	0.112	0.112	0.184	0.61	0.242	0.236	0.343	0.277	0.163	0.221	0.205
	18.5-24.9	0.112	0.141	0.127	0.226	0.23	0.268	0.309	0.427	0.364	0.189	0.281	0.234
	25.0-29.9	0.146	0.183	0.167	0.256	0.42	0.296	0.345	0.511	0.442	0.218	0.330	0.267
	30.0-34.9	0.154	0.201	0.181	0.289	0.88	0.327	0.384	0.549	0.479	0.235	0.337	0.286
	35.0-39.9	0.185	- -	0.185	0.312	0.27	0.322	0.396	0.567	0.533	0.243	0.396	0.294
	> 39.9	-		-	-	0.43	0.343	-	0.570	0.570	0.255	0.349	0.302

F – female, M – male

of individuals who did not eat meat products, but consumed dairy products, and the group of individuals who did the opposite (Table 8). A statistically significant difference was found between individuals who did not use either dairy nor meat products in their diet and, finally, other individuals, with the exception of individuals who consumed meat products but abstained from dairy products. Individuals whose diet contained both meat and dairy products had over 3.5 μg g^{-1} lead and over 0.31 μg g^{-1} cadmium in their hair, whereas for the others the figures were lower. The lowest amounts of these metals were detected in hair of individuals, who abstained from both these types of products, and the recorded values in this group exhibited the lowest variation (8.2% and 8.5%, respectively). This is consistent with the results of studies by NABRZYSKI and GAJEWSKA (1984). They showed that milk contains approx. 14 μg dm^{-3} Cd and 9 μg g^{-1} Pb, acid tvarog approx. 1.6 μg g^{-1} Cd and 2.0 μg g^{-1} Pb, hard cheese 4.8 μg g^{-1} Cd and 5.9 μg g^{-1} Pb, meat from approx. 2 to 10 μg g^{-1} Cd and from 4 to 38 μg g^{-1} Pb, while sausages and processed meats from 3 to 9 μg g^{-1} Cd and from 2 to 9 μg g^{-1} Pb, respectively. The uptake of Cd for an adult consuming dairy products during a week can reach 10 μg Cd and 13 μg Pb, while for one consuming meat and its processed products the uptake is approx. 47 μg Cd and approx. 77 μg Pb.

Table 8

Influence of a diet on the content of lead and cadmium in hair of persosns living in Central Pomerania

Consumption of		*n*	Pb				Cd			
meat products	dairy products		*x**	*A*	SD	*V%*	*x**	*A*	SD	*V%*
+	+	69	3.54	0.94-9.74	0.45	12.7	0.315	0.033-0.769	0.046	14.5
+	-	127	2.74	0.60-9.39	0.48	17.5	0.236	0.045-0.678	0.041	17.4
-	+	77	3.10	0.10-7.90	0.30	9.7	0.274	0.051-0.773	0.035	12.3
-	-	143	2.08	0.72-7.15	0.17	8.2	0.141	0.027-0.542	0.012	8.5

n – number of persons, *x** – average values, *A* – range

Thus, an overall living standard, including the environment, may have a significant effect on concentrations of metals in the human organism (BENCKO 1995). For this reason, hair may constitute a suitable material for the evaluation of environmental metal exposure, including lead and cadmium. In this study, the type of environment is connected with the place of residence (rural vs. urban areas) of individuals in the analyzed population. Since inhabitants of big cities are more at risk of being exposed to metals in different forms, the levels of lead and cadmium in hair of examined individuals living in big cities were higher than those in inhabitants of rural areas, irrespective of their age group (Table 9), with the differences being

Table 9

Influence of the environment on content of lead and cadmium in hair of the subjects divided according to gender and age. Number of persons given in parentheses

Metals	Place of living	Female					Male				
		0-15 years	16-25 years	26-50 years	51-75 years	0-75 years	0-15 years	16-25 years	26-50 years	51-75 years	0-75 years
Pb	village	0.86 (20)	1.65 (30)	2.22 (23)	2.88 (34)	2.02(107)	1.51 (23)	2.21 (21)	3.56 (23)	3.56 (31)	2.79 (98)
	town	2.21 (17)	2.96 (25)	3.48 (31)	4.32 (30)	3.39(103)	3.98 (20)	4.56 (30)	5.38 (32)	5.47 (26)	4.91(108)
Cd	village	0.085	0.174	0.246	0.156	0.174	0.100	0.230	0.411	0.276	0.257
	town	0.172	0.313	0.385	0.284	0.303	0.246	0.405	0.549	0.398	0.417

Table 10

The content of lead and cadmium in hair of ill and healthy subjects

Disease	*n*	Pb				Cd			
		*x**	*A*	SD	*V%*	*x**	*A*	SD	*V%*
Prostatic hypertrophy	38	4.83	0.51 - 9.05	0.51	10.6	0.318	0.035 - 0.678	0.050	16.7
Arteriosclerosis	59	3.24	0.43 - 7.15	0.38	11.7	0.331	0.040 - 0.704	0.042	12.7
Type 2 diabetes	32	2.11	0.26 - 7.08	0.33	15.6	0.264	0.044 - 0.621	0.021	7.9
Arterial hypertension	85	1.73	0.10 - 6.38	0.24	13.9	0.182	0.030 - 0.593	0.025	13.7
Coronary disease	47	3.18	0.38 - 8.02	0.27	8.5	0.249	0.038 - 0.688	0.024	9.6
Anaemia	36	5.09	0.47 - 9.24	0.69	13.5	0.147	0.027 - 0.603	0.032	21.8
Renal hypofunction	28	3.30	0.31 - 7.26	0.45	13.6	0.415	0.053 - 0.769	0.028	6.7
Allergie	43	5.47	0.55 - 9.74	0.49	9.0	0.509	0.051 - 0.773	0.041	8.0
Without the symptoms of sick leave	175	305	0.32 - 9.39	0.32	10.5	0.257	0.033 - 0,720	0.033	12.8

n – number of persons, *x** – average values, *A* – range statistically significant. It was only between children living in these two diverse environments no significant difference in cadmium levels were found. Moreover, it was observed that in each age group, the differences between males living in these two different environments were higher than in the case of women. The effect of the environment on concentrations of lead and cadmium in human hair was shown in studies by many authors (ZABOROWSKA, WIERCIŃSKI 1997, NOWAK, CHMIELNICKA 2000, MORTADA et al. 2002, CHOJNICKA et al. 2005). Inhabitants of more urbanized or industrialized areas had much higher levels of these metals in their hair than people living in rural or even suburban areas.

Analysis of hair may be a suitable method for determination of the mineral composition of the organism (RADOMSKA et al. 1991). Both, excess and deficiency of metals in the body are conducive to the development of different diseases. This problem has been investigated by many researchers (ŁUKASIAK et al. 1998, KOŁMOGOROW et al. 2000, FORTE et al. 2005, BOCCA et al. 2006). Based on elemental analysis, conclusions may be drawn on a possible relationship between a specific disease and detected deficiency or surplus of bioelements. Inferences may also be presented regarding increased risk of incidence of specific diseases, suggesting a potentially harmful effect of toxic elements on the metabolism of a patient. REN et al. (1997) and STRZELCZYK et al. (2001) showed a significant correlation between content of certain metals in hair and development of malignant cells. With respect to copper deficiency, formation of elastin in walls of blood vessels and collagen in the skeletal system are disturbed and hypochromic anaemia is frequently observed (KAŁUŻA et al. 2001). Analysis of the mineral composition of hair is an analytical test, which in combination with other laboratory analyses and the clinical picture, may be applied in diagnostics of pathological conditions (GUTTERTIGE 1990, MIEKELEY et al. 2001). Within this study, the effect of certain chronic diseases on content of lead and cadmium in hair has also been investigated (Table 10). As suggested by the collected data, there is a relationship between certain chronic diseases among the examined patients and the level of the above-mentioned elements in their hair. Individuals suffering from allergies had the highest levels of these metals in their hair. Patients suffering from prostatic hypertrophy or anaemia had much more lead (4.83 and 5.09 μg g^{-1}, respectively) in their hair than healthy individuals. These differences were statistically significant (p = 0.05). In turn, patients suffering from hypertension or type II diabetes had much lower levels of lead than people with no disease symptoms. In patients with renal hypofunction, a much higher level of cadmium was observed than that in healthy individuals, in whom much higher metal concentrations were detected in comparison to patients suffering from anaemia or arterial hypertension. These differences were statistically significant (p =0.05). An elevated level of cadmium copmared to that found in healthy people was recorded in hair of patients with arteriosclerosis or prostatic hypertrophy.

From the medical point of view, one of the factors affecting levels of heavy metals in hair may be consumption of vitamins or hormones (Kutsky 1981), or medications (Roe 1976). Based on hair analysis, Stanbury et al. (1983) and Štupar et al. (2007) investigated the metabolism of metals under the influence of certain hereditary diseases. Each new observation during such analysis contributes to our improved understanding of metal metabolism. Broadening of the knowledge to include the physiology of trace elements facilitates clinical applications or makes them possible. Results of mineral analysis of hair is used at present more frequently than in the past. The application of mineral hair analysis in healthy individuals may indicate certain disorders in the organism and potential diseases. In combination with other analytical data, it may constitute a complementary diagnostic method for practicing physicians. It would be complementary since in clinical practice it may not be used in individual evaluations due to difficulties with reliable interpretations. These problems result from a large number of factors affecting metal contents in hair. The effect of some of such factors are a subject of this paper.

CONCLUSIONS

1. The mean content of lead and cadmium in hair of individuals living in Central Pomerania is 3.20 $\mu g\ g^{-1}$ and 0.284 $\mu g\ g^{-1}$, respectively, and it increases with age, reaching the highest level at the age of approx. 40 years in case of cadmium, and at the age of approx. 60 years in case of lead.

2. Most of the examined individuals had from 2 to 4 $\mu g\ g^{-1}$ lead and from 0.1 to 0.3 $\mu g\ g^{-1}$ cadmium in their hair.

3. Examined females had lower content of lead and cadmium in their hair than males.

4. Content of analyzed metals in hair was significantly affected by diet. People abstaining from dairy and meat products had much lower contents of lead and cadmium in their hair than those using these products in their diet.

5. The place of residence also has an effect on the concentrations of these metals in hair of examined people. Inhabitants of rural areas had lower metal contents in their hair than those living in big cities.

6. The height and weight of examined individuals did not have an effect on concentrations of lead and cadmium in their hair. It was only among children that significant dependence was found between these parameters.

7. The bigger the obesity of examined individuals, the more cadmium detected in their hair.

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