原著論文
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High Toxic Metal Levels in Scalp Hair of Infants and Children

Hiroshi Yasuda, Toshie Yonashiro, Kazuya Yoshida, Takeshi Shibazaki,
Tomiko Ishii, and Toyoharu Tsutsui

Research Laboratory, La Belle Vie Inc., Tokyo 103-0006, Japan

Abstract

We measured the toxic metal contents in 5846 hair samples from infant to elderly to estimate their exposure levels. The geometric means of hair mercury levels in male adults showed age-related increase from 2.4 $\mu g/g$ at high-teens up to a peak of 5.9 $\mu g/g$ at 50's, and then decreased with further aging. In children, at the age of 4-15 years, a small peak of 3.1 $\mu g/g$ was observed. The hair mercury levels in female were significantly lower than those in male.

A similar, age-related accumulation profile with gender difference was also observed with arsenic in hair. The mean arsenic levels in male age-dependently increased up to 98 ng/g at the 80's elderly, with a small peak of 66 ng/g at the age of 10-15 years. A similar, but lower age-related accumulation pattern was observed in female.

Cadmium and lead showed another type of accumulation profile: the highest levels were observed in the infants aged 1-3 years both for male and female, with neither marked age-dependency nor gender difference. Aluminium also exhibited a similar accumulation profile with the highest levels at infants and young children, as well as cadmium and lead.

These findings indicate that the toxic metals are classified to two types based on their accumulation profiles, and some elements having high accumulation in infants and children, namely cadmium, lead and aluminium, should be reconsidered and surveyed as risky metal to the young generation.

Key words : Toxic metals; Age-related accumulation; Gender difference; Infants; Children

Introduction

The scalp hair is a unique kind of tissue containing hair-specific protein "keratin" which is rich in cysteine residue capable of binding with metals, and functions to excrete them from the body. In facts, high levels of toxic metals such as mercury, cadmium, arsenic or lead in the hair tissue of people exposed to toxic metal pollutions have been reported[1-5]. Thus, hair mineral analysis has been widely used for assessment of environmental exposure[6-9], for evaluation of nutritional status, for diagnosing diseases and in forensic science[10,11].

For the last several years, we have been analysing hair minerals in people from infant to elderly, in order to assess relationship between the minerals and physical or mental disorder. In this study, we measured the toxic metal contents in scalp hair of total 5846 Japanese, and found out that there are two types in accumulation profile of toxic metals. In addition, it was suggested that infants and children are suffered from exposure to some toxic metals.

Materials and Methods

Hair mineral analysis

Scalp hair samples from 5846 subjects aged 1-88 years (male: 2201; female: 3645) in the Tokyo metropolitan area were collected. The hair from the back of the head, 2-3 cm in length, was cut close to the scalp. The hair sample of 75 mg was weighed into 50ml

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Correspondence : Hiroshi Yasuda, Ph. D.
Research Laboratory, La Belle Vie Inc.,
8-4 Nihonbashi-Tomizawacho, Chuo-ku,
Tokyo, 103-0006
Fax: +81-3-3668-5001
E-mail: yasuda@LBV.jp

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Table 1. Mean value and standard deviation of the logarithms of of hair toxic metal levels

Age (years)	Sex	Number	Hg			As			Cd		Pb		Al	
			Mean	SD	t-Test	Mean	SD	t-Test	Mean	SD	Mean	SD	Mean	SD
1-3	Male	35	3.383	0.463		1.685	0.461		1.568	0.649	3.041	0.334	4.040	0.239
	Female	27	3.385	0.257		1.599	0.245		1.477	0.454	3.087	0.472	3.994	0.226
4-9	Male	35	3.497	0.332		1.763	0.278		1.212	0.444	2.730	0.327	4.003	0.284
	Female	33	3.384	0.346		1.643	0.242		1.363	0.449	2.922	0.482	4.090	0.342
10-15	Male	39	3.498	0.263		1.804	0.339		1.212	0.402	2.801	0.430	3.854	0.314
	Female	34	3.338	0.302	*	1.577	0.468	*	1.169	0.457	2.720	0.386	3.795	0.324
16-19	Male	42	3.379	0.370		1.622	0.324		1.046	0.476	2.682	0.499	3.565	0.408
	Female	150	3.316	0.298		1.400	0.406	**	1.118	0.507	2.685	0.492	3.583	0.286
20-29	Male	426	3.468	0.260		1.630	0.327		1.099	0.422	2.722	0.435	3.571	0.351
	Female	876	3.320	0.319	***	1.285	0.387	***	1.191	0.449	2.818	0.491	3.636	0.362
30-39	Male	653	3.588	0.293		1.690	0.326		1.136	0.437	2.744	0.441	3.571	0.343
	Female	867	3.408	0.291	***	1.346	0.411	***	1.203	0.406	2.828	0.462	3.621	0.364
40-49	Male	419	3.690	0.306		1.693	0.400		1.133	0.427	2.710	0.487	3.534	0.339
	Female	576	3.461	0.319	***	1.365	0.428	***	1.186	0.435	2.757	0.502	3.612	0.329
50-59	Male	311	3.770	0.320		1.756	0.334		1.071	0.460	2.660	0.421	3.542	0.322
	Female	523	3.552	0.276	***	1.389	0.429	***	1.220	0.422	2.794	0.526	3.641	0.352
60-69	Male	162	3.745	0.363		1.865	0.329		1.133	0.443	2.610	0.515	3.582	0.370
	Female	352	3.536	0.255	***	1.496	0.421	***	1.248	0.406	2.696	0.472	3.668	0.343
70-79	Male	64	3.674	0.294		1.896	0.245		1.146	0.460	2.607	0.400	3.500	0.390
	Female	170	3.490	0.264	***	1.596	0.392	***	1.303	0.438	2.692	0.571	3.679	0.385
80 -	Male	15	3.470	0.614		1.991	0.310		1.113	0.306	2.403	0.555	3.467	0.309
	Female	37	3.243	0.447		1.712	0.343	**	1.162	0.327	2.460	0.528	3.445	0.378

The mean value and standard deviation of the logarithms of toxic metal levels are shown.
Statistical significance was determined using the Welch's t-test.
*: $p < 0.05$ **: $p < 0.01$ ***: $p < 0.001$

plastic tube, and washed twice with acetone and then with 0.01% Triton solution, according to the procedures recommended by the Hair Analysis Standardization Board[12]. The washed hair sample was mixed in 10 ml of 6.25% tetra methyl ammonium hydroxide (TMAH, Tama Chemical) and 50 μl of 0.1% gold solution (SPEX Certi Prep.), and then dissolved at 75 ℃ with shaking for 2 hours. After cooling the solution to room temperature and adjusting its volume gravimetric, the obtained solution was used for mineral analysis. The mineral concentrations were measured with inductively coupled plasma mass spectrometry (ICP-MS; Agilent-7500). The toxic metal contents in hair were expressed as ng/g hair (ppb) or μg/g (ppm).

Statistical methods

The hair toxic metal levels were distributed in lognormal manner, and so the geometric rather than arithmetic means were used as representative of hair mineral levels. For statistical analysis, the values of mineral levels were converted to the logarithm. Statistical significance was determined using the Welch's t-test.

Results

The toxic metal contents in hair samples were distributed in nearly lognormal profile. Table 1 shows the population number studied, average of the logarithms of hair metal levels and standard deviation for every age-class. The geometric mean of hair mercury levels in male adults showed age-related increase from the lowest level of 2.4 μg/g at high-teens up to a peak of 5.9 μg/g at 50's, and then decreased with further aging (Fig. 1). In children, at the age of 4-15 years, a small peak of 3.1 μg/g was observed. A similar, but not marked age-related pattern was also observed in female. The mean mercury levels of the female samples varied from 2.0 to 3.6 μg/g, and these values were significantly lower than those for males ($p < 0.001$).

A similar, age-dependent accumulation profile with gender difference was also observed on the arsenic level (Fig. 2). In males, the mean arsenic levels increased to a small peak of 64 ng/g at the age of 10-15 years, and after the bottom value of 42 ng/g at near 20 years re-increased up to 98 ng/g with aging until over eighty. In females, the mean hair arsenic levels age-dependently increased from 19 to 52 ng/g. The gender difference was more marked at adult generations elder than twenty years old.

In contrast, cadmium and lead showed a different accumulation pattern from mercury and arsenic: the highest levels were observed in the infants aged 1-3 years both for male and female, and in adults these levels were not increased age-dependently (Fig. 3 and 4). In addition, there was no marked gender-difference observed for these toxic metals, but rather the tendency of being higher in female than in male.

Aluminium also showed an accumulation profile similar to that of cadmium and lead. The highest aluminium levels were observed in infants and children aged around 1-9 years both for male and female, and the mean levels in adults were 1/3-1/4 of those in the young children (Fig. 5).

Discussion

Mercury, especially methylmercury, is an environmental pollutant with neurotoxic action, and is well known as the causative agent that induced Minamata disease[1]. This neurotoxic organic mercury, not only has long residence time in the environment, but also bio-accumulates in the food chain, eventually causing exposure to humans, mostly via consumption of fishes such as tuna, swordfish, mackerel and shark[9]. Thus, in Japan, hair mercury levels among general populations have been surveyed to estimate the current mercury exposure levels[9,13].

In this study, we surveyed the accumulation levels of five toxic metals, namely neurotoxic mercury and lead, carcinogenic cadmium and arsenic, and aluminium in the hair samples from 5846 subjects aged 1 to 88 years and examined the influence of age and gender on the accumulation of these toxic elements.

The mean hair mercury levels showed an age-related, biphasic increase with a small peak at the age of 4-15 years and main peak at 50's, and then decreased with further aging (Fig. 1). A similar accumulation

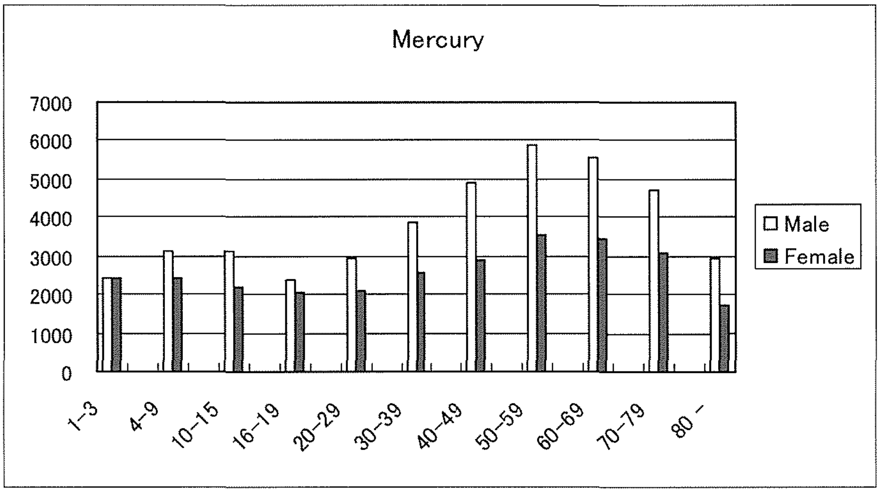

Fig. 1. Hair mercury levels in Japanese
Open and closed column represents the geometric mean of hair mercury contents (ng/g hair) for male and female subjects aged 1-3, 4-9, 10-15, 16-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years over, respectively.

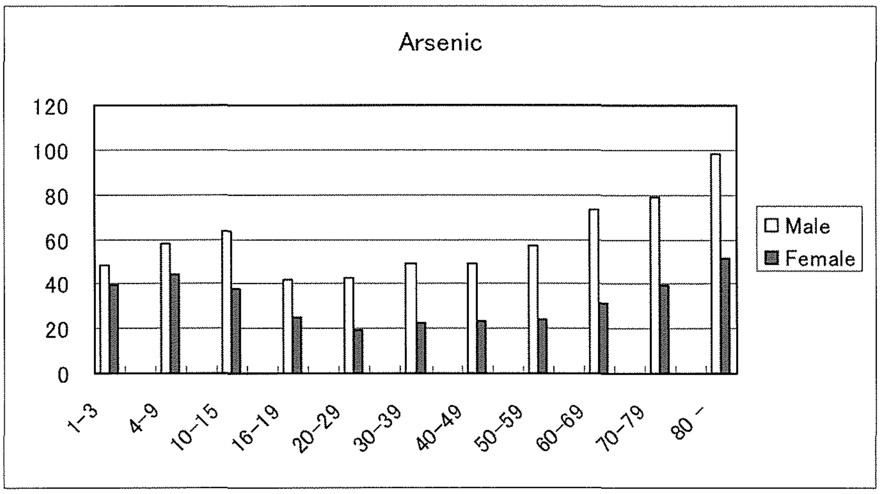

Fig. 2. Hair arsenic levels in Japanese
Open and closed column represents the geometric mean of hair arsenic contents (ng/g hair) for male and female subjects aged 1-3, 4-9, 10-15, 16-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years over, respectively.

pattern was also observed in female, but not marked as in males. The gender difference in mercury accumulation was more apparent at ages elder than twenty years old. These results were consistent with those in the residence in Chiba prefecture, in which the hair mercury levels were higher than those in the districts of the west Japan, as reported by Yasutake et al[9]. These findings suggest that the residence in the Tokyo metropolitan area has higher mercury accumulation, compared to those in the other areas.

On the mechanism of the gender difference, some hormonal control might be involved in the mercury uptake by human hair, since a marked sex difference in the tissue uptake and elimination has been reported in methylmercury-treated animals[14]. In addition, the lower value for female may be partly due to the low amounts of fish consumption and the high incidence of artificial waving among women[13,15].

Arsenic was also found to exhibit an age- and gender-dependent accumulation profile similar to that of mercury: the hair arsenic levels in adults showed age-related increase up to 80' s, with a small peak at the age of 10-15 years (Fig. 2).

In contrast, cadmium, lead and aluminium levels in hair exhibited another type of age-related accumulation profile: the highest levels were observed

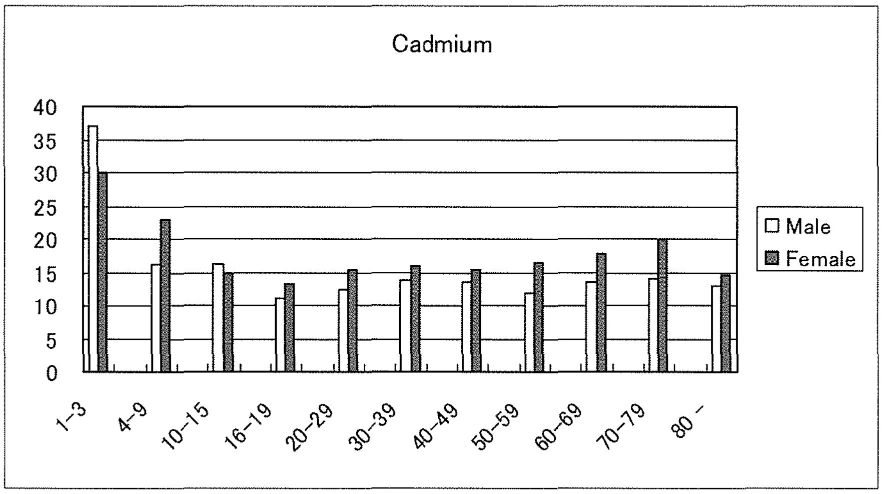

Fig. 3. Hair cadmium levels in Japanese

Open and closed column represents the geometric mean of hair cadmium contents (ng/g hair) for male and female subjects aged 1-3, 4-9, 10-15, 16-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years over, respectively.

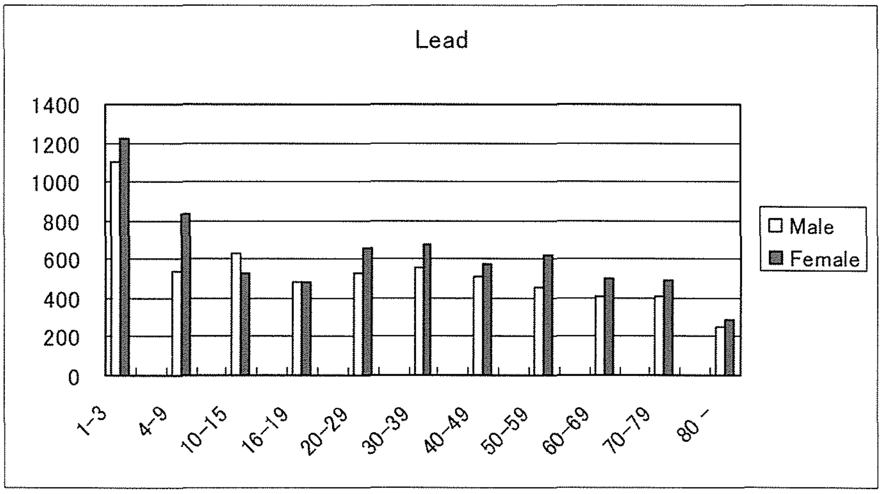

Fig. 4. Hair lead levels in Japanese

Open and closed column represents the geometric mean of hair lead contents (ng/g hair) for male and female subjects aged 1-3, 4-9, 10-15, 16-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years over, respectively.

in the infants aged 1-3 years both male and female, and in adults these levels were relatively constant and so age-dependency and gender difference was not marked as mercury and arsenic (Fig. 3-5).

These findings indicate that toxic metals are classified to two groups on the base of hair accumulation profile. The first group consists of mercury and arsenic, which show a biphasic age-related accumulation pattern with marked gender difference. The second group consists of cadmium, lead and aluminium, which have a characteristic accumulation profile exhibiting the highest levels in infants and young children. Thus, infants and children must be considered and cared as a high-risk group for adverse health effects caused by the latter toxic metals.

Lead is well known, as well as mercury, to cause some fraction of neuro-developmental disabilities [2,4,16,17]. The World Health Organization has recognized that low-level environmental lead exposure (blood lead levels <10 μg/dl) is associated with intellectual impairments in children. Cadmium is also a serious pollutant, and induces learning disorder in infants[18-20]. It accumulates in the kidney with ageing, and induces renal dysfunction and osteoporosis[21,22].

The high accumulation of toxic metals in infants indicates that they are under the circumstance of high exposure to these toxic elements, maybe through infant formulas, weaning foods and breast milk, and also through toys and tools etc. In fact, Eklund and Oskarsson [23] reported that soy-based formulas contained approximately six times more cadmium than cow's milk formulas, and cereal-based formulas had 4-21 times higher levels. Thus, compared to breast milk-fed children, the intake of dietary cadmium from weaning foods can be up to 12 times higher in the children fed infant formula[23].

Aluminium is another element that needs to be monitored in infants[24,25]. McGraw et al.[26] reported that high aluminium was contained in milk formulas for infants. Compared to human breast milk containing 5-20 μg aluminium per litre, the aluminium concentrations were 10- to 20- fold higher in cow's milk-based formulas and 100-fold higher in soy-based formulas[27]. Bishop et al.[28] reported that in preterm infants, prolonged intravenous feeding with solutions containing aluminium is associated with impaired neurological development.

High accumulation of toxic metals in infants may be explained by their low ability of renal excretion activity. When immature or reduced kidney function occurs in infants, aluminium from cow's milk- or soy-based formulas is accumulated and stored thereafter. Freundlich et al.[29] reported that in two infants with severe kidney failure, the absorption and retention of aluminium from a cow's milk-based formula resulted in clinical toxicity. Thus, infants are at increased risk of taking high amount of aluminium and retaining absorbed aluminium in their bodies. We need to well understand about the unique characters and biological actions of aluminium[30,31] and to reconsider its risk.

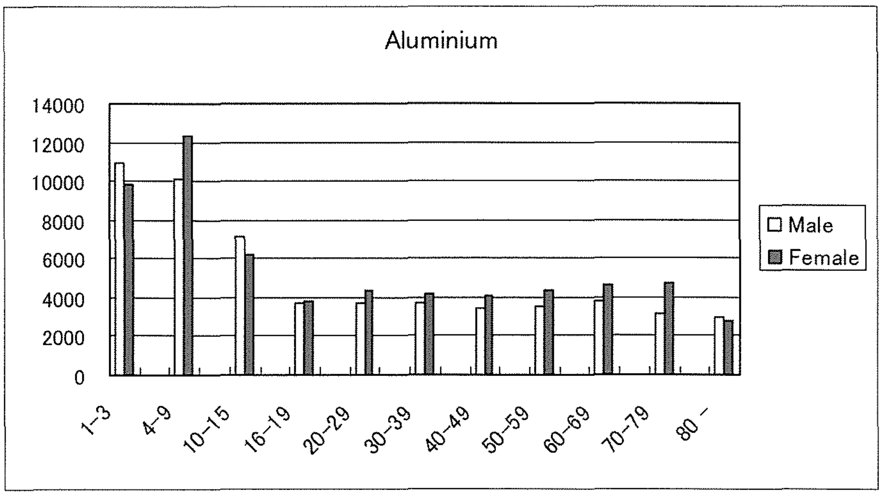

Fig. 5. Hair aluminium levels in Japanese
Open and closed column represents the geometric mean of hair aluminium contents (ng/g hair) for male and female subjects aged 1-3, 4-9, 10-15, 16-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years over, respectively.

Conclusion

This study demonstrates that toxic metals are classified into two groups, on the base of their accumulation profiles. Mercury and arsenic are grouped to the first type, that is characteristic of their marked age-dependency and gender-difference in accumulation profile. Lead, cadmium and aluminium are grouped to the second type that is characteristic of high accumulation in infants and children. It is noted that young children are under compound exposure to these toxic metals. These findings suggest that the second type of toxic metals should be considered as toxic element having the possibility of high risk to younger generation and have to be monitored.

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