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Blood Cadmium Concentration of Residents Living near Abandoned Metal Mines in Korea

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The purpose of this study was to investigate demographic and lifestyle variables and blood cadmium concentrations in residents living near abandoned metal mines in Korea. Blood cadmium concentrations were measured in 15,161 subjects living around abandoned metal mines (exposed group, n = 14,464) and compared with those living in designated control areas (control group, n = 697). A questionnaire was provided to all subjects to determine age, gender, mine working history, times of residence, smoking habits and dietary water type. The geometric mean (95% confidence intervals) of blood cadmium concentration (1.25 [1.24-1.27] µg/L) in the exposed group was significantly higher than in the control group (1.17 [1.13-1.22] µg/L). Mean residence time and mine working history in the exposed group were significantly higher than in the control group. Blood cadmium concentrations increased with increasing age, and residence time in both groups, and blood cadmium concentrations were higher in current-smokers than in non-smokers in both groups. This study shows the geometric mean of blood cadmium concentration in abandoned mining areas are higher than in non-mining areas in the general adult Korean population.

Keywords: Blood Cadmium; Abandoned Metal Mine; Korea

INTRODUCTION

Metal mining developed in Korea from the late 19th Century, but in late 1970s mines were abandoned due to changes in the structure of industry and economic status. In 2000, 906 metal mines had been closed and abandoned without any environmental management (1). Most were heavy metal mines that severely contaminated nearby agricultural soils and streams (2). Furthermore, they were abandoned without proper environmental remediation. Cadmium is of particular concern because it is highly toxic and exposure leads to accumulation in the human body. Cadmium used to be used in nickel-cadmium batteries, pigments, manufacturing, electroplating, and plastic stabilizers, and thus, had access to all aspects of the environment (3). Food grown in contaminated soil or water lead to cadmium accumulation (4) and is a major source of human exposure. Heavy metal contamination of soil, water and agricultural products and their impacts on residents is an ongoing social issue in Korea. Several studies have identified health risks to residents living near abandoned mines (5-8) and the Ministry of Environment (MOE) is concerned about the effects of agricultural and drinking water contamination on the health of local populations. Accordingly, a health survey was planned on residents living near abandoned mines in combination with detailed investigation of soil and water near abandoned mines.

In 2007, as part of the comprehensive environmental health plan for the control and prevention of environmental contamination, the MOE planned a national bio-monitoring survey of the blood concentrations of three metals, lead, cadmium, and mercury, in residents living around 350 abandoned metal mines classified as contaminated and possible threats to health.

The present study was undertaken to determine the blood

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cadmium concentrations of residents living in the vicinities of 350 abandoned metal mines and to compare these concentrations with those of control subjects. In addition, we also evaluated relations between blood cadmium levels and demographic and lifestyle factors.

MATERIALS AND METHODS

Subjects

This study was undertaken to survey of environmental contamination in 906 abandoned metal mines in Korea by the MOE. Three hundred and fifty abandoned mines were included in this survey, Fig. 1 show the locations of the abandoned mines. A detailed description of the study population and the method of data collection have been published previously (9). A total of 15,612 subjects (14,883 subjects living in the vicinity of the 350 abandoned mines and 729 control subjects living in five nearby provinces not affected by abandoned mine areas) all older than 20 yr old were considered for the survey. However, some participants were excluded due to missing questionnaire information or lack of data on blood cadmium concentration. Finally, 15,072 potentially exposed residents and 608 controls agreed to participate. Before conducting the survey, the approval was obtained from the Institutional Review Board of the National Institute of Environmental Research.

Questionnaire study

Personal face to face interviews were conducted to document demographic and lifestyle information. Ages were recorded at time interview and categorized into six age groups (20-39, 40-49, 50-59, 60-69, 70-79, and ≥ 80 yr). Smoking habits were divided into three categories: current smoker, ex-smoker, and nonsmoker. Ex-smokers were defined as those that had quit smoking at least 1 yr prior to the survey, and current smokers were defined as those who still smoked or who had smoked less than 1 yr before the survey. Information regarding working history in mines was also obtained. Total residence times in regions affected by abandoned mining sites were categorized < 20, 20-39, 40-59, and ≥ 60 yr, and sources of drinking water were categorized as: public common ground water, private groundwater, tap water, and others such as purified water, commercial bottled water, and water from mineral springs.

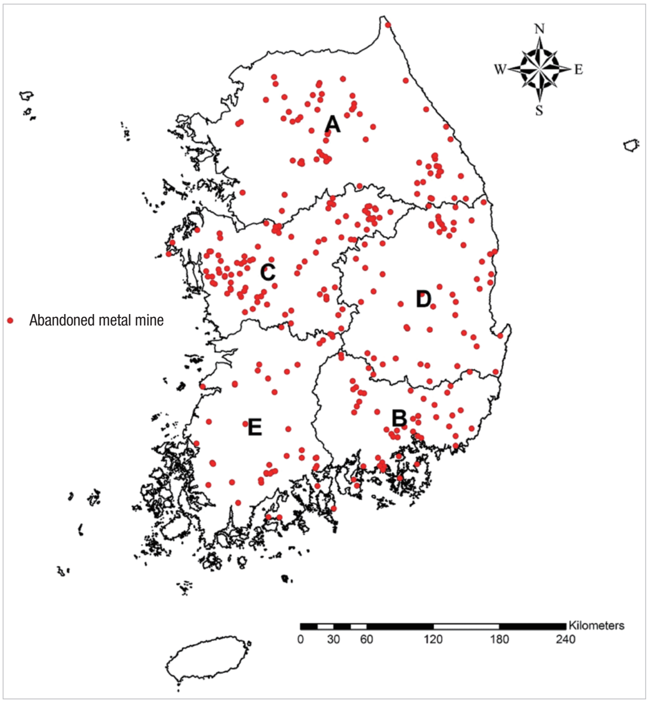

Fig. 1. Locations of 350 abandoned metal mines.

Sampling and analysis

Blood sampled for cadmium measurements was placed in 3 mL sodium heparin metal-free tube (Vacutainer® cap) to prevent clotting, mixed well, cold stored and transported to a laboratory where they were stored at -70°C. Before analysis, the samples were shaken again to prevent clotting.

Blood cadmium analysis

For blood cadmium analysis, Triton X-100 2 mL and ammonium phosphate ($[NH_4]_2HPO_4$) 2 g in 1,000 mL deionized water was prepared as 0.2% Triton X-100 medium modified reagent. A Cd 1,000 μg/dL standard solution (1,000 ppm) was prepared by cadmium 0.1 mL with deionized water 10 mL. Samples were prepared by mixing medium modified reagent 0.9 mL, cadmium standard solution 0.05 mL, and blood 0.05 mL. The cadmium standard solution (1,000 ppm, Sigma®, Fluka, Buchs, Switzerland) was used to calibrate an atomic absorption spectrophotometer (AAS, VARIAN spectro AA 240Z, Varian, Belrose, Australia). To ensure the accuracy of the blood cadmium analysis, a quality control was performed using the blood standard samples (Whole Blood Metal Control, Bio-Rad®, California, USA). A Zeeman atomic absorption spectrometer-graphite furnace (VARIAN spectro AA 240Z, Varian, Belrose, Australia) was used to analyze blood samples in a flameless manner. The samples measured under the detection limit were not found.

Quality assurance and control

Blood cadmium analyses were carried out by the Department of Preventive Medicine, College of Medicine Dong-A University and this laboratory was certified by the Ministry of Labor in Korea. As an external quality assurance and control program, the institute passed the German external quality assessment scheme (GEQUAS) of the Friedrick Alexander University (a standard quality assurance scheme for institutions measuring chemicals at low concentrations) with both occupational and environmental medical range programs. For the internal quality assurance and control program, commercial reference materials were obtained from Seronorm (Whole Blood Metals Control). The coefficients of variation were 4.2%, 2.9% for two blood cadmium samples (reference values, 0.67, 5.8 μg/L), respectively. To determine the method detection limit, blood samples were obtained from non-exposed individuals whose blood cadmium levels were below 1 μg/L. Then, blood cadmium concentrations were determined in five preparations across the 5 days, the limits of detection were calculated according to IUPAC guidelines using three standard deviations. The method detection limit for blood cadmium in this study was 0.19 μg/L.

Statistical analysis

STATA/SE 11.1 was used for the statistical analysis. Because blood cadmium levels showed a lognormal distribution, geometric means (GMs) were used after logarithmic transformation in this study. In order to determine the general characteristics of subjects, cross tabulation analysis according to gender was carried out. ANOVA test was used to examine relation between blood cadmium concentrations and gender, residence time, alcohol consumption, smoking habits, working history in mines, and dietary water type. And simultaneously depending on the level of each factor between exposure and control groups, independent t-test was conducted. We fit multiple-regression analysis of log-blood cadmium concentration to the independent variables to find risk factors that influenced blood cadmium concentrations. A 5% level of significance was used throughout.

Ethics statement

This study protocol was approved by the Chung-Ang University institutional review board for medical research and other studies involving human subjects (No. 2007-1). Informed consent was confirmed by IRB. All subjects in exposed or control groups signed an informed consent.

RESULTS

General characteristics

The study subjects were 15,072 adults, which were allocated to an exposed group (5,864 males and 8,600 females) and a con-

Table 1. General characteristics of the study subjects

Characteristics	Target population No. (%)		*P* value*
	Exposure (n = 14,464)	Control (n = 608)	
Sex			0.839
Male	5,864 (40.5)	249 (41.0)	
Female	8,600 (59.5)	359 (59.1)	
Age (yr) (Mean ± SD)	63.86 ± 14.31	63.54 ± 12.80	0.547
≤ 39	837 (5.8)	37 (6.1)	0.279
40-49	1,156 (8.0)	46 (7.6)	
50-59	2,261 (15.6)	98 (16.1)	
60-69	4,422 (30.6)	214 (35.2)	
70-79	4,588 (31.7)	168 (27.6)	
80 ≤	1,200 (8.3)	45 (7.4)	
Smoking status			0.906
Non-smoker	8,854 (61.2)	374 (61.5)	
Current-smoker	3,552 (24.6)	145 (23.9)	
Ex-smoker	2,058 (14.2)	89 (14.6)	
Working History of mines			< 0.001
No	12,535 (86.7)	591 (97.2)	
Yes	1,929 (13.3)	17 (2.8)	
Period of residence (yr)			< 0.001
≤ 19	2,301 (15.9)	164 (27.0)	
20-39	2,589 (17.9)	173 (28.5)	
40-59	5,198 (35.9)	163 (26.8)	
60 ≤	4,376 (30.3)	108 (17.8)	
Type of dietary water			< 0.001
Public ground water	6,877 (47.6)	288 (47.4)	
Private groundwater	3,917 (27.1)	61 (10.0)	
Tap water	2,793 (19.3)	176 (29.0)	
Others	877 (6.1)	83 (13.7)	
Geographical area			< 0.001
A	3,291 (22.8)	148 (24.3)	
B	2,273 (15.7)	186 (30.6)	
C	4,355 (30.1)	171 (28.1)	
D	2,824 (19.5)	53 (8.7)	
E	1,721 (11.9)	50 (8.2)	

**P* values for chi-square-test and *P* for trend test.

Table 2. Geometric means of blood cadmium concentration (μg/L) in people living near abandoned mines and in controls by geographical area

Target population	Area	Male		Female		Total	
		No.	G.M. (95% CI)	No.	G.M. (95% CI)	No.	G.M. (95% CI)
Exposure	Total	5,864	1.14 (1.12-1.16)	8,600	1.33 (1.32-1.35)	14,464	1.25 (1.24-1.27)
	A	1,385	0.96 (0.93-1.00)	1,906	1.13 (1.10-1.16)	3,291	1.06 (1.03-1.08)
	B	838	1.46 (1.40-1.53)	1,435	1.60 (1.55-1.66)	2,273	1.55 (1.51-1.59)
	C	1,894	1.11 (1.08-1.15)	2,461	1.28 (1.25-1.32)	4,355	1.21 (1.18-1.23)
	D	1,093	1.19 (1.14-1.24)	1,731	1.38 (1.33-1.42)	2,824	1.30 (1.27-1.33)
	E	654	1.24 (1.19-1.29)	1,067	1.46 (1.42-1.51)	1,721	1.37 (1.34-1.41)
Control	Total	249	0.99 (0.92-1.06)	359	1.12 (1.06-1.17)	608	1.06 (1.02-1.11)
	A	78	0.87 (0.75-1.00)	70	1.13 (1.03-1.23)	148	0.98 (0.90-1.07)
	B	65	1.30 (1.14-1.48)	121	1.38 (1.26-1.52)	186	1.35 (1.25-1.46)
	C	64	0.82 (0.74-0.91)	107	0.83 (0.77-0.90)	171	0.83 (0.78-0.88)
	D	23	1.15 (0.94-1.39)	30	1.21 (1.01-1.45)	53	1.18 (1.04-1.34)
	E	19	1.07 (0.86-1.34)	31	1.21 (1.02-1.44)	50	1.16 (1.01-1.32)
Korean National Survey* 2007		776	0.92 (0.88-0.96)	1,486	1.08 (1.05-1.11)	2,262	1.02 (1.00-1.05)

*2nd Korean National Human Exposure and Bio-monitoring Examination. G.M., geometric mean; CI, confidence interval.

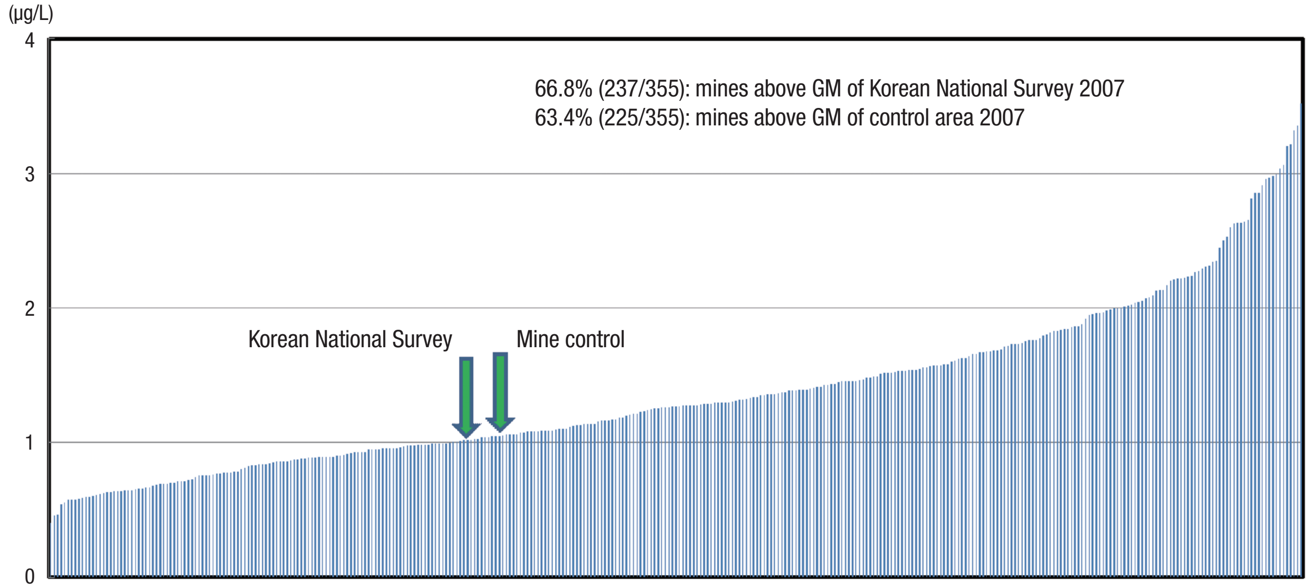

Fig. 2. Distribution of geometric means of blood cadmium concentrations (μg/L) in subjects living near the 350 abandoned mines. GM, Geometric mean.

trol group (249 males and 359 females). The distributions of age, gender and smoking status were similar between in the two groups. Mean age was 63.9 ± 14.3 yr in the exposed group and 63.5 ± 12.8 yr in the control group. The proportions of male subject were 40.5% and 41.0% in the exposed and control groups, respectively (Table 1).

Blood cadmium concentration

Blood cadmium concentrations were measured in 15,072 adults living near abandoned mines in Korea. Table 2 provides data on the GMs of blood cadmium concentrations of subjects in five administrative provinces, and also presents the reference Korean blood cadmium concentration data from the Second Korean National Human Exposure and Bio-monitoring Examination, which was conducted in 2007 (Fig. 2). The GM of blood cadmium concentration of all subjects in abandoned mines was 1.25 μg/L (95% confidence interval [CI], 1.24-1.27 μg/L), which was significantly higher than the 1.06 μg/L of the control subjects (95% CI, 1.02-1.11 μg/L).

Table 3 shows the GMs of blood cadmium concentration with respect to social-demographic variables. The GMs of blood cadmium concentration in exposed group were greater in females (1.33 μg/L; 95% CI, 1.32-1.35 μg/L) than in males (1.14 μg/L; 95% CI, 1.12-1.16 μg/L), and this was also found in controls. Multiple linear regression analysis using log-transformed blood cadmium concentration as a dependent variable and all other study variables as independent variables was carried out to evaluate the associations between all study variables and blood cadmium concentration (Table 4). Log-transformed blood cadmium concentration in the exposed group was found to be 1.24 times higher than in the control group after adjusting for all other relevant variables.

Table 3. Geometric mean concentration of blood cadmium (μg/L) in the exposed and control groups

Characteristics	Exposure (n = 14,464) G.M. (95% CI)	Control (n = 608) G.M. (95% CI)	*P* value
Total	1.25 (1.24-1.27)	1.17 (1.13-1.22)	0.011
Age (yr)			
≤ 39	0.83 (0.80-0.87)	0.75 (0.61-0.92)	0.371
40-49	1.25 (1.20-1.30)	1.06 (0.87-1.30)	0.101
50-59	1.29 (1.25-1.32)	1.24 (1.11-1.38)	0.540
60-69	1.26 (1.24-1.29)	1.21 (1.14-1.29)	0.324
70-79	1.30 (1.27-1.32)	1.20 (1.12-1.29)	0.096
80 ≤	1.36 (1.31-1.41)	1.25 (1.07-1.46)	0.404
P value	< 0.001	< 0.001	
Period of residence (yr)			
≤ 19	1.07 (1.04-1.10)	1.07 (0.98-1.16)	0.958
20-39	1.28 (1.25-1.31)	1.16 (1.06-1.26)	0.033
40-59	1.31 (1.29-1.34)	1.30 (1.21-1.39)	0.810
60 ≤	1.27 (1.25-1.30)	1.18 (1.07-1.30)	0.219
P value	< 0.001	< 0.001	
Smoking			
Non-smoker	1.23 (1.21-1.25)	1.17 (1.11-1.24)	0.158
Current-smoker	1.41 (1.39-1.44)	1.28 (1.18-1.40)	0.041
Ex-smoker	1.11 (1.08-1.14)	1.02 (0.91-1.14)	0.223
P value	0.000	0.006	
Working History of mines			
Yes	1.28 (1.24-1.32)	1.23 (0.92-1.65)	0.819
No	1.25 (1.24-1.27)	1.17 (1.12-1.22)	0.013
P value	0.222	0.730	
Type of dietary water			
Public groundwater	1.27 (1.26-1.29)	1.11 (1.04-1.18)	0.000
Private groundwater	1.18 (1.15-1.20)	1.04 (0.89-1.22)	0.135
Tap water	1.29 (1.25-1.32)	1.32 (1.22-1.42)	0.621
Other	1.35 (1.29-1.42)	1.14 (1.03-1.25)	0.019
P value	< 0.001	0.001	

**P* values for independent t-test; *P* value for one way ANOVA. G.M. geometric mean.

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Table 4. Multiple linear regression model results of the associations between log-transformed blood cadmium concentration and demographic and lifestyle variables

Independent variables		10^{β}	95% CI	*P* value for t-test $\beta = 0$
Intercept		0.51	0.47-0.55	< 0.001
Gender	Male	1.00 (reference)		
	Female	1.22	1.19-1.26	< 0.001
Age (yr)	≤ 39	1.00 (reference)		
	40-49	1.44	1.35-1.53	< 0.001
	50-59	1.38	1.31-1.46	< 0.001
	60-69	1.35	1.28-1.42	< 0.001
	70-79	1.39	1.32-1.46	< 0.001
	80 ≤	1.38	1.30-1.46	< 0.001
Smoking status	Non-smoker	1.00 (reference)		
	Current-smoker	1.02	0.98-1.06	0.350
	Ex-smoker	1.24	1.20-1.28	< 0.001
Working history at mines	No	1.00 (reference)		
	Yes	1.04	1.01-1.07	0.024
Period of residence (years)	≤ 19	1.00 (reference)		
	20-39	1.08	1.04-1.12	< 0.001
	40-59	1.07	1.03-1.11	< 0.001
	60 ≤	1.07	1.03-1.11	< 0.001
Type of dietary water	Public groundwater	1.00 (reference)		
	Private groundwater	1.08	1.04-1.13	< 0.001
	Tab water	1.02	0.99-1.05	0.184
	Others	0.99	0.97-1.02	0.639
Geographical area	A	1.00 (reference)		
	B	1.42	1.37-1.47	< 0.001
	C	1.13	1.08-1.18	< 0.001
	D	1.19	1.15-1.23	< 0.001
	E	1.12	1.09-1.16	< 0.001
Control	Yes	1.00 (reference)		
	No	1.24	1.17-1.31	< 0.001

Covariates as gender, age, smoking status, working history of mines, period of residence, type of dietary water, geographic area, and control group were included.

DISCUSSION

The GM of blood cadmium concentration reported in the Korean National Human Exposure and Bio-monitoring Examination was 1.02 μg/L (95% CI, 1.00-1.05 μg/L), and international guideline values for non-smoking adults was 1.0 μg/L (10). However the blood cadmium concentration in this study was lower than that in residents of Goseong area, as there was a report suspecting cadmium-related health symptoms among the residents near three abandoned Copper mine, in which geometric mean of blood cadmium was 2.92 μg/L (9). The difference in blood cadmium concentration of the abandoned mining area, even for the same term used, as a result of the amount of cadmium due to various factors may be considered, such as exposure to local residents in the different sources according to the actual amount of cadmium in abandoned mines, geographical location and surrounding environment, the diversity path of the state of pollution, the differences in the amount and the pathway of food intake, exposure of the population variability of biological differences. Ikeda et al. (11) showed the regional difference of blood cadmium concentration in the general populations of Asian countries as Japan 1.82 μg/L, Korea 1.37 μg/L, China 0.61 μg/L, Taiwan 0.83 μg/L, Malaysia 0.74 μg/L. However, reported levels in the United States 0.47 μg/L (12), and Germany 0.44 μg/L (13) were much lower. And the differences of blood cadmium concentration between exposure and control may be caused by duration living metal mines area and differences in proportion of age. Also it was known that the causes of a high concentration in the Asian population are varied. Food accounts for a major part of the cadmium exposure are known. Rice is the staple diet of Koreans, Japanese and other Asian countries (4, 14), and in Japan, cadmium concentrations in rice is showed a higher tendency than in other countries (15). Additional study through the measurement for cadmium content of the food intake of each resident, the analysis and the observations are thought to be complementary.

In this study, the GMs of blood cadmium concentration in exposed group were greater in females than in males and this finding was also found in controls. That fact is consistent with that of a previous study conducted in 193 youth in 2001. Also mean blood cadmium levels were found to be higher in females (0.69 μg/L) than in males (0.57 μg/L) (16). This difference is believed to be related to body iron levels, because during a state of iron deficiency cadmium absorption is increased (17). In animal experiments iron uptake was attributed to metal movement protein (metal transporter protein) in the small intestine and cadmium is absorbed via the same route (18).

In the present study, the GMs of blood cadmium concentration were found to increase with age and smoking status, after adjusting for other variables. These findings are consistent with the results of the Second Korean National Human Exposure and Bio-monitoring Examination, conducted during the period from August 2007 to April 2008. The GMs of blood cadmium concentration of current smoker were found to be significantly higher than in non-smoker. Smoking is known to be a cause of exposure, because cadmium in cigarette becomes airborne combustion process (19-21). We also found that the GM of blood cadmium concentration was significantly higher in smokers than in nonsmokers and past smokers. Cadmium has toxic effects for kidney as abnormal functions of proximal tubules and glomerulus, results from a long-term cadmium exposure in kidney. And then the urinary cadmium concentration is increased because of kidney malfunctions. The urinary cadmium concentration is good index for kidney malfunctions. On the other hand blood cadmium concentration is good index for exposure level of Cadmium.

This study has several limitations that should be borne in mind. First, this study was designed to determine biological levels of cadmium in populations living near the abandoned mines. However we did not measure levels of cadmium in the environments. Second, the number of control subjects was assigned relatively small as compared with the exposed group. Many studies have been performed on the risks of abandoned mines focused on environmental contamination of cadmium, and then it can be used only for reference group for the comparison of exposed group. However human exposure studies by abandoned metal mines were relatively rare. Therefore, this study is considered to be a valuable research in the environmental health epidemiology. The strength of this study is that it was performed on a nationwide basis and included all abandoned mines. Accordingly, we believe this study provides meaningful information about cadmium exposure levels for those living near abandoned metal mines.

In conclusion, this study shows that the GM of blood cadmium concentration in abandoned mine residents is higher than those living in control areas and from the Second Korean National Human Exposure and Bio-monitoring Examination. We assume that the elevated blood cadmium concentration in the abandoned mine residents have been affected by the abandoned mine sites in Korea.

DISCLOSURE

The authors have no conflicts of interest to disclose.

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