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

Young-Seoub Hong,1,2 Byung-Kook Lee,3 Jung-Duck Park,4 Joon Sakong,5 Jae-Wook Choi,6 Jai-Dong Moon,7 Dae-Seon Kim,8 and Byoung-Gwon Kim1,2

1Department of Preventive Medicine, College of Medicine, Dong-A University, Busan; 2Heavy Metal Exposure Environmental Health Center, Dong-A University, Busan; 3Institute of Environmental and Occupational Medicine, College of Medicine, Soonchunhyang University, Asan; 4Department of Preventive Medicine, College of Medicine, Chung-Ang University, Seoul; 5Department of Preventive Medicine, College of Medicine, Yeungnam University, Daejeon; 6Department of Preventive Medicine, College of Medicine, Konkuk University, Seoul; 7Department of Preventive and Occupational Medicine, Chonnam National University Hwasun Hospital, Hwasun; 8Department of Environmental Health Research, National Institute of Environmental Research, Incheon, Korea

Received: 14 November 2013
Accepted: 20 March 2014

Address for Correspondence:
Byoung Gwon Kim, MD
Department of Preventive Medicine, College of Medicine, Dong-A University, 32 Daesigongwon-ro, Seo-gu, Busan 602-714, Korea
Tel: +82.51-240-2770, Fax: +82.51-253-5729
E-mail: medikim@dau.ac.kr

This study was supported by the Dong-A University research fund 2014.

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...
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 ground water, tap water, and others such as purified water, commercial bottled water, and water from mineral springs.

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 ([NH₄]₂HPO₄) 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®). 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 Friedrich 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 assur-
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 control group (654 males and 608 females) (Table 1). The study subjects were 15,072 adults, which were allocated to an exposed group (5,864 males and 8,600 females) and a control group (64 males and 60 females).

**Table 1. General characteristics of the study subjects**

| Characteristics | Exposure          | Control          | P value* |
|-----------------|-------------------|------------------|----------|
| Age (yr) (Mean ± SD) | 63.86 ± 13.31 | 63.54 ± 12.80 | 0.547    |
| Smoking status | Non-smoker 8,854 (61.2) | 374 (61.5) | 0.06     |
| Working History of mines | No 12,535 (86.7) | 591 (72.2) | < 0.001  |
| Period of residence (yr) | 63.54 | < 0.001 |
| Type of dietary water | Public ground water 6,877 (47.6) | 288 (47.4) | < 0.001  |
| Geographical area | A 3,291 (22.8) | 148 (24.3) | < 0.001  |
| 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                 | 1,933 | 1.19 (1.14-1.24) | 1,731 | 1.30 (1.23-1.33) | 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) |

*2nd Korean National Human Exposure and Bio-monitoring Examination. G.M., geometric mean; CI, confidence interval.
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 $1.25 \text{ } \mu g/L$ (95% confidence interval [CI], $1.24-1.27 \text{ } \mu g/L$), which was significantly higher than the $1.06 \text{ } \mu g/L$ of the control subjects (95% CI, $1.02-1.11 \text{ } \mu g/L$).

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 ($1.33 \text{ } \mu g/L$; 95% CI, $1.32-1.35 \text{ } \mu g/L$) than in males ($1.14 \text{ } \mu g/L$; 95% CI, $1.12-1.16 \text{ } \mu g/L$), 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 ($\mu g/L$) in the exposed and control groups

| Characteristics | Exposure (n = 14,464) | Control (n = 608) | P value |
|-----------------|------------------------|------------------|---------|
| G.M. (95% CI)   | G.M. (95% CI)          | P                 |
| 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   |
| 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   |
| 40-49           | 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 ground water | 1.27 (1.26-1.29)   | 1.11 (1.04-1.18)  | 0.000   |
| Private ground water | 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.
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 in Korean near abandoned mines showed a higher tendency 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 in Korean near abandoned mines showed a higher tendency 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 concentra-
tion 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 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.

REFERENCES

1. Ministry of Environment (Korea). White paper of environment 2009. Gwacheon: Ministry of Environment, 2010.
2. Yang JE, Skouensen JG, Ok YS, Yoo KY, Kim HJ. Reclamation of abandoned coal mine waste in Korea using lime cake byproducts. Mine Water Environ 2006; 25: 227-32.
3. Page AL, Chang AC. Cadmium. Berlin: Spring-Verlag, 1986.
4. Zhang ZW, Moon CS, Watanabe T, Shimbo S, He FS, Wu YQ, Zhou SF, Su DM, Qu JB, Ikeda M. Background exposure of urban populations to lead and cadmium: comparison between China and Japan. Int Arch Occup Environ Health 1997; 69: 273-81.
5. Park JD, Park CB, Choi BS, Kang EY, Hong YP, Chang IW, Chun BY, Yeh MH. A study on urinary cadmium concentration and renal indices of inhabitant in an abandoned mine area. Korean J Prev Med 1998; 31: 424-39.
6. Chung JH, Kang PS, Kim CY, Lee KS, Hwang TY, Kim GT, Park JS, Park SY, Kim DS, Lim OT, et al. Blood Pb, Urine Cd and health assessment of residents in the vicinity of abandoned mines in Gyeongsangbuk-do. Korean J Occup Environ Med 2005; 17: 225-37.
7. Sakong J. Health risks associated with contamination of environment by abandoned mines. Yeongnam Univ J Med 2007; 24: S212-20.
8. Kim S, Kwon HJ, Cheong HK, Choi K, Jang JY, Jeong WC, Kim DS, Yu S, Kim YW, Lee KY, et al. Investigation on health effects of an abandoned metal mine. J Korean Med Sci 2008; 23: 452-8.
9. Kim NS, Sakong J, Choi JW, Hong YS, Moon JD, Lee BK. Blood lead levels of residents living around 350 abandoned metal mines in Korea. Environ Monit Assess 2012; 184: 4139-49.
10. Wilhelm M, Ewers U, Schulz C. Revised and new reference values for some trace elements in blood and urine for human biomonitoring in environmental medicine. Int J Hyg Environ Health 2004; 207: 69-73.
11. Ikeda M, Zhang ZW, Shimbo S, Watanabe T, Nakatsuka H, Moon CS, Matsuda-Inoguchi N, Higashikawa K. Urban population exposure to lead and cadmium in east and south-east Asia. Sci Total Environ 2000; 249: 373-84.
12. Korea Center for Disease Control and Prevention. National human exposure assessment survey, 1999-2000. Cheonguwen: Korea Center for Disease Control and Prevention, 2000.
13. Becker K, Kaus S, Krause C, Lepom P, Schulz C, Seiwert M, Seifert B. German Environmental Survey 1998 (GerES III): environmental pollutants in blood of the German population. Int J Hyg Environ Health 2002; 205: 297-308.
14. Eunha O, Lee EL, Lim H, Jang Y. Human multi-route exposure assessment of lead and cadmium for Korean volunteers. J Prev Med Public Health 2006; 39: 53-8.
15. Moon CS, Zhang ZW, Shimbo S, Watanabe T, Moon DH, Lee CU, Lee BK, Ahn KD, Lee SH, Ikeda M. Dietary intake of cadmium and lead among the general population in Korea. Environ Res 1995; 71: 46-54.
16. Chang SS, Kyun YH, Bae JS, Roh YM, Jan IG. Blood cadmium concentration according to exposure of smoking in adolescence. J Korean Soc Sch Health 2001; 14: 207-14.
18. Ryu DY, Lee SJ, Park DW, Choi BS, Klaassen CD, Park JD. Dietary iron regulates intestinal cadmium absorption through iron transporters in rats. Toxicol Lett 2004; 152: 19-25.

19. Hwang HJ, Moon DH, Park MH, Kim JH, Hwang YS, Lee YH. A study on concentration of five heavy metals in tobacco on the market. Inje Med J 1998; 19: 713-21.

20. Sugita M, Izuno T, Tatemichi M, Otahara Y. Cadmium absorption from smoking cigarettes: calculation using recent findings from Japan. Environ Health Prev Med 2001; 6: 154-9.

21. Shin JY, Lim JH, Park SG, Lee JN, Jang M, Huh CS, Kang DH, Hong YC. Influence of smoking on blood cadmium concentration in university students. J Prev Med Public Health 2004; 37: 225-31.