Bull Environ Contam Toxicol (2009) 83:71–74
DOI 10.1007/s00128-009-9722-8

Effects of Mercury Released from Gold Extraction by Amalgamation on Renal Function and Environment in Shanxi, China

L. Tian · H. F. Guo · A. Gao · X. T. Lu · Q. Y. Li

Received: 14 April 2008 / Accepted: 7 April 2009 / Published online: 22 April 2009

Abstract We investigated the distribution of mercury and its impacts on the renal function of the residents living in mercury-contaminated area due to gold extraction by amalgamation in some area of Shanxi, China. The results showed that mercury concentrations in contaminated air in four seasons were 79–240 ng/m^3. The mercury concentration in the river across contaminated area was also high. The mercury contents in the grain were higher than those in the non-mercury contaminated area. The urinary mercury and urinary β_2-microglobulin for the residents living in the contaminated area were 1.24 ± 3.80 μg/L and 228.98 ± 4.34 μg/g Cr, higher than those in the non-mercury contaminated area.

Keywords Mercury · Renal function · Gold extraction by amalgamation · Environment

Mercury is an important industrial and environmental pollutant, which exists in the natural world widely. Mercury can be readily re-emitted to the atmosphere from any site in which it has been deposited, due to its volatility (Schroeder and Munthe 1998). Therefore, the release of mercury to environment by human activities can seriously contaminate local environment, but may also affect the regional and global environment. Mercury is harmful to the environment and human health. Recent years, many scholars focused upon the impacts of mercury on human health. Studies have demonstrated that mercury contamination has become one of the most serious problems which threaten the subsistence of human beings (Iwata et al. 2007; Clarkson 2002; Tsuji et al. 2003). The study to investigate mercury contamination in regional environment and its impacts on the renal function of human beings was carried out in some region in Shanxi Province, China. The mercury amalgamation was used for gold extraction in previous several years. At present, majority of gold mines was shut down, which resulted in the tremendous reduction of mercury contamination in the local environment. Since mercury can persist for long time in the environment and also large amount of mercury was dumped, the mercury contamination is expected to present in that region. In this study the distribution of mercury in the local air, water and grain was investigated. The renal function of residents in the local region was also explored. The final goal was to understand mercury pollution in this area and possible health risks associated with mercury in gold extraction processes.

Materials and Methods

This is a cross sectional study. A and B villages were chosen as contaminated areas in which gold extraction by amalgamation with many years of manufacture record was used. Mercury contamination was severe. C and D villages in the same areas, but not have gold mines, were considered

L. Tian (✉) · A. Gao
Department of Occupational and Environmental Health, School of Public Health and Family Medicine, Capital Medical University, 100069 Beijing, People's Republic of China
e-mail: tian_lin@163.com

H. F. Guo
Taiyuan Center for Disease Control and Prevention, 030001 Taiyuan, People's Republic of China

X. T. Lu · Q. Y. Li
School of Public Health, Shanxi Medical University, 030001 Taiyuan, People's Republic of China

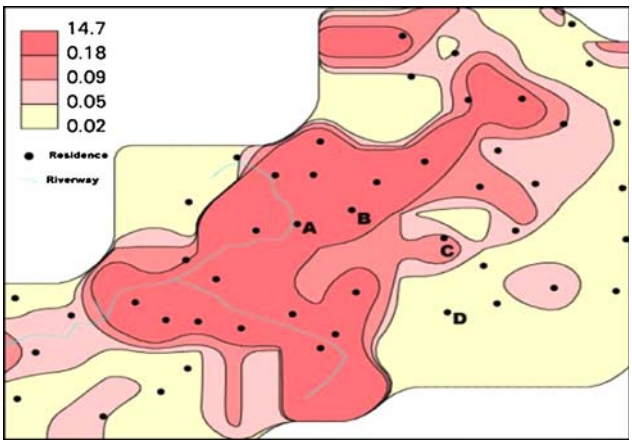

Fig. 1 The distribution of mercury pollution grade in surface soil of study area

as the non-mercury contaminated area (control area). Mercury concentration in the soil of polluted region is 4.52 mg/kg, compared with 0.06 mg/kg in control area (Fig. 1). Study population was randomly selected from people living at least 5 years in the contaminated and control areas. Three hundred and ninety four people were enrolled, of which 203 from the contaminated area and 191 from the control area. All subjects met the study requirements and provided informed consent, medical history and exposure history to mercury. The life style including smoking habit and alcohol drinking was comparable between two groups.

The mercury level was determined in air, river water, drinking water and grain. The air mercury concentration was measured using HY-100 Intelligent Air Pump. The samples were taken at 1.5 m above the ground at 0.5 L/min, 60 min for each collection. Air was sampled 4 times in January, April, July and October 2006 to allow for four seasoned variation in contaminated area. Air was sampled only in April 2006 in control area. At each site, the measurement was carried out twice a day for three consecutive days. River water and drinking water samples were collected with polypropylene jars which were soaked and treated with HNO_3 diluted and ultrapure water. Samples were kept at 4°C until analysis. Grain such as millet and maize was collected from farmer's homes. In the laboratory, all grain samples were air dried, ground in a ceramic disc mill, and sieved to 100 μm.

A random urine sample in a polyethylene bottle was collected. The urine sample was divided into two parts immediately. One part was used for mercury measurement and the other was assayed for renal function. The urine samples were stored frozen (at −20°C) prior to analysis.

The mercury concentration in air, water, urine and grain was determined by the cold vapor atomic fluorescence spectrophotometry method (Tang et al. 2007). The method involved sample digestion with HNO_3, $KMNO_4$ and H_2SO_4. Samples were analyzed by use of cold vapor atomic fluorescence spectroscopy analyzer (XGY1011A). The detection limit was 0.01 ng/g.

Replicates were performed to ensure the quality of the assay. Also, blanks, spiked samples and standard solutions were analyzed at the beginning of each batch of samples to ensure accuracy and precision of the analyses. Recoveries on matrix spikes of mercury of air, water, grain and urine were at the range of 90%–110%.

Urinary β_2-microglobulin (β_2-MG) and urinary albumin (mALB) was determined with endpoint colorimetric analysis. The urinary *N*-acetyl-β-D-glucosaminidase (NAG) activity was measured by kinetic method and creatinine was determined by Jaffe photometric method (reagent from Roche Diagnostics; detection limit 0.01 nmol/L). The concentrations of urinary NAG, urinary mALB and urinary β_2-MG were adjusted by the urinary creatinine concentration.

Statistical Package for Social Sciences (SPSS, version 11.0) was used for data analysis. The log transformed mean values of NAG and β_2-MG were presented. Independent *T* test and *F* test were used to evaluate the difference between the exposed and control groups. Pearson correlation analysis was used for correlation coefficients among urinary mercury, urinary β_2-MG, urinary NAG, and urinary mALB in exposed group. The results of a statistical test were considered statistically significant if $p < 0.05$.

Results and Discussion

The air mercury concentrations in both contaminated and control areas did not exceed national ambient air quality standards (0.3 μg/m^3), but mercury concentrations in contaminated area were significantly higher than that in control area. Mercury concentrations were the highest in summer and the lowest in winter (Table 1).

Mercury levels in drinking water did not exceed the standard (0.001 mg/L) and there was no significant difference in two areas (Table 2). Mercury contents in river

Table 1 The air mercury concentrations in two areas (ng/m^3, $\bar{x} \pm s$)

Season	Contaminated area		Control area	
	N	Mercury	N	Mercury
Spring	23	100.0 ± 10.0*	20	9.80 ± 1.25
Summer	29	240.0 ± 20.0*,△		
Autumn	31	128.0 ± 14.7*		
Winter	24	79.40 ± 7.55*		

* Compared with the control area, $p < 0.05$; △ compared with the control area, spring, autumn and winter, $p < 0.05$

Table 2 The mercury contents in drinking water and river (μg/L, $\bar{x} \pm s$)

Working area	Drinking water		River	
	N	Mercury	N	Mercury
Control area	6	0.023 ± 0.005		
Contaminated area	4	0.025 ± 0.006	2	20.0 ± 6.0

Table 3 The grain mercury contents in two areas (mg/kg, $\bar{x} \pm s$)

Working area	N	Millet	Maize
Control area	10	0.003 ± 0.001	0.004 ± 0.001
Contaminated area	12	0.006 ± 0.003*	0.013 ± 0.006*

* Compared with the control area, $p < 0.05$

water exceeded groundwater environment quality standard (0.001 mg/L) (Table 2).

The mercury contents in millet and maize did not exceed the standard in two areas, but there was significant difference between the two areas. Mercury contents in millet and maize in contaminated area were significantly higher than those of in control area (Table 3).

Urinary mercury concentration and levels of three renal function parameters were shown in Table 4. There was significant difference in mercury concentration between the contaminated area and the control area. Mercury concentration in contaminated area was significantly higher than that in control area. The level of urinary β_2-MG in contaminated area was significantly higher than that of in control area. There were not significant differences in levels of urinary NAG and urinary mALB between contaminated area and control area. The correlation coefficients between urinary mercury and urinary β_2-MG, urinary NAG and urinary mALB for the contaminated area were analyzed and listed in Table 5.

It is reported that gold extraction by amalgamation was world-widely used, and so the problem of mercury contamination was astonishingly serious (Feng et al. 2006). Although artisanal gold mining activities have been officially prohibited in China since 1996, a few illegal mines are still operating in some areas. In addition, there is significant mercury contamination in ecosystems surrounding area of past mercury mining.

Table 5 The correlation coefficients among urinary mercury and urinary β_2-MG, urinary NAG and urinary mALB contents in the contaminated area

Biomarkers	β_2-MG		NAG		mALB	
	r	*p*	*r*	*p*	*r*	*p*
Mercury	0.404	0.000**	0.178	0.014*	0.042	0.570

* $p < 0.05$; ** $p < 0.01$

The main part of the mercury contamination comes from artisanal mining operations. Gold extraction by amalgamation was rampant 10 years ago. During the gold mining activities mercury was released into the environment by using amalgamation for gold extraction. Additionally, after the closure of the mining works, mercury continued to seep into the environment through wastes stocked in the spoil heaps resulting in an increase of mercury concentrations in air, soil and surface water.

The mercury concentration of soil in contaminated area was 65 times higher than that of control area. Control area had the similar global chemistry environment background as investigative area, but not affected by mercury pollution. The mercury content of soil in contaminated area was 14 times higher than Environmental Quality Standard for Soil. Although gold extraction by amalgamation had stopped in majority regions, a lot of solid wastes had got into the river by wind erosion and water erosion so that a main across river was contaminated by mercury in different levels. The mercury content was 19 times higher than national standard in river water. The mercury contents of grain in contaminated area did not exceed the standard, but mercury contents in contaminated area were significantly higher than those of control area. The mercury content of drinking water did not exceed national standard.

Mercury concentrations in air were 79–240 ng/m^3 in four seasons in contaminated area, it did not exceed the national standard of 0.3 μg/m^3, but significantly higher than that of control area and higher than that of China most city atmosphere. Liu et al. (2002) measured total gaseous mercury concentrations in the range of 6–10 ng/m^3 during winter in Beijing. Feng et al. (2002) measured concentrations of total gaseous mercury in the range of 5–15 ng/m^3 in Guiyang, Guizhou Province. The average particulate mercury concentrations in Changchun, Jilin Province, is about 0.5 ng/m^3, rising to as high as 2 ng/m^3 in winter

Table 4 Comparison of all biomarkers in urine

Working area	N	Mercury (G ± *s*, μg/L)	β_2-MG (G ± *s*, μg/gCr)	NAG ($\bar{x} \pm s$, U/gCr)	mALB ($\bar{x} \pm s$, mg/gCr)
Control area	191	0.51 ± 1.30	158.02 ± 4.01	12.24 ± 8.00	11.06 ± 14.62
Contaminated area	203	1.24 ± 3.80*	228.98 ± 4.34*	11.94 ± 7.37	11.72 ± 13.53

* Compared with the control area, $p < 0.05$

(Fang et al. 2001). This observation demonstrated that atmosphere environment in investigation area was contaminated due to gold extraction activities.

Mercury exposure posed a significant threat to human health. The residents in contaminated area may expose themselves to mercury by multiple ways. For instance, mercury released into atmosphere in amalgam process can be absorbed into the human body through the respiratory tract, gastrointestinal tract, skin and others. The mercury in atmosphere through the dry and wet deposition was attached to the soil, crops. The residents in the place consumed local food which made mercury accumulate in their body. Finally, since local tailing dumps were randomly stacked, resulted in mercury contaminated surrounding water and soil, further through contaminated soil cultivation, resulted in ecosystem secondary pollution, causing harm to the human body.

Kidney was the major organ for mercury to accumulate in the body. Urine analysis has been the most common way to evaluate exposure to metallic mercury in man (Cornelis et al. 1996; Malm 1998; Laitinen et al. 1998). Urinary mercury is considered as a biomarker of exposure to mercury. NAG is located in lysosomes where it plays a role in breakdown of glycoprotein. A low level of NAG is found in normal urine. NAG activity in urine is enhanced when renal proximal tubular epithelial cells are damaged (Chia et al. 1994). β_2-MG, a low molecular weight protein, can be readily filtered through the glomerular membrane and is reabsorbed by the proximal tubular epithelial cells where it is catabolized. Reabsorption is highly effective, with up to 99.97% of the filtered proteins being reabsorbed. The excretion of urinary β_2-MG is enhanced when the function of renal tubular reabsorption is obstructed. (Lauwerys and Bernard 1989; Mueller et al. 1989). Urinary mALB is helpful to judge early damage of glomerular filtration membrane. Urinary β_2-MG concentration in contaminated area was significantly higher than that of control area. Significant correlation ($r = 0.404$, $p < 0.01$) was found between urinary mercury and urinary β_2-MG contents of residents in contaminated area. It is evident that mercury pollution has caused early health hazards on renal function of residents. β_2-MG was more sensitive than NAG to detect renal injury, it could serve as a sensitive biomarker for detecting early renal damage.

In summary, the mercury concentration in air, soil, grain in contaminated area was higher than that of control area. It is evident that a great part of mercury remains in soil, river and air in the area after discontinuing manufacture activities for nearly 10 years. The mercury pollution has affected the local resident's renal function to a less extent. Urinary β_2-MG could be as an early sensitive indicator for the renal damage caused by mercury.

References

Chia KS, Mutti A, Tan C, Ong HY, Jeyaratnam J, Ong CN, Lee E (1994) Urinary *N*-acetyl-β-D-glucosaminidase activity in workers exposed to inorganic lead. Occup Environ Med 51:125–129. doi:10.1136/oem.51.2.125

Clarkson TW (2002) The three modern faces of mercury. Environ Health Perspect 110:11–23

Cornelis R, Heinzow B, Herber RF, Christensen JM, Poulsen OM, Sabbioni E, Templeton DM, Thomassen Y, Vahter M, Vesterberg O (1996) Sample collection guidelines for trace elements in blood and urine. J Trace Elements Med Biol 10:103–127

Fang F, Wang Q, Li J (2001) Atmospheric particulate mercury concentration and its dry deposition flux in Changchun City, China. Sci Total Environ 281:229–236. doi:10.1016/S0048-9697(01)00849-X

Feng X, Sommar J, Lindqvist O, Hong Y (2002) Occurrence, emissions and deposition of mercury during coal combustion in the province Guizhou, China. Water Air Soil Pollut 139:311–324. doi:10.1023/A:1015846605651

Feng X, Dai Q, Qiu G, Li G, He L, Wang D (2006) Gold mining related mercury contamination in Tongguan, Shaanxi Province, PR China. Appl Geochem 21:1955–1968. doi:10.1016/j.apgeochem.2006.08.014

Iwata T, Sakamoto M, Feng X, Yoshida M, Liu XJ, Dakeishi M, Li P, Qiu G, Jiang H, Nakamura M, Murata K (2007) Effects of mercury vapor exposure on neuromotor function in Chinese miners and smelters. Int Arch Occup Environ Health 80:381–387. doi:10.1007/s00420-006-0144-1

Laitinen J, Liesivuori J, Savolainen H (1998) Urinary NAG and GAG as biomarkers of renal effects in exposure to 2-alkoxyalcohols and their acetates. J Occup Environ Med 40:595–600. doi:10.1097/00043764-199807000-00003

Lauwerys R, Bernard A (1989) Preclinical detection of nephrotoxicity: description of tests and appraisal of their health significance. Toxicol Lett 46:13–29. doi:10.1016/0378-4274(89)90113-6

Liu S, Nadim F, Perkins C, Carley RJ, Hoag GE, Lin Y, Chen L (2002) Atmospheric mercury monitoring survey in Beijing, China. Chemosphere 48:97–107. doi:10.1016/S0045-6535(02)00026-7

Malm O (1998) Gold mining as a source of mercury exposure in the Brazilian Amazon. Environ Res 77:73–78. doi:10.1006/enrs.1998.3828

Mueller PW, Smith SJ, Steinberg KK, Thun MJ (1989) Chronic renal tubular effects in relation to urine cadmium levels. Nephron 52:45–54. doi:10.1159/000185581

Schroeder WH, Munthe J (1998) Atmospheric mercury—an overview. Atmos Environ 32:809–822. doi:10.1016/S1352-2310(97)00293-8

Tang SL, Feng XB, Qiu JR, Yin GX, Yang ZC (2007) Mercury speciation and emissions from coal combustion in Guiyang, southwest China. Environ Res 105:175–182. doi:10.1016/j.envres.2007.03.008

Tsuji JS, Williams PR, Edwards MR, Allamneni KP, Kelsh MA, Paustenbach DJ, Sheehan PJ (2003) Evaluation of mercury in urine as an indicator of exposure to low levels of mercury vapor. Environ Health Perspect 111:623–630