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Impacts of Mercury Pollution Controls on Atmospheric Mercury Concentration and Occupational Mercury Exposure in a Hospital

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Abstract Mercury (Hg) and Hg-containing products are used in a wide range of settings in hospitals. Hg pollution control measures were carried out in the pediatric ward of a hospital to decrease the possibility of Hg pollution occurring and to decrease occupational Hg exposure. Total gaseous Hg (TGM) concentrations in the pediatric ward and hair and urine Hg concentrations for the pediatric staff were determined before and after the Hg pollution control measures had been implemented. A questionnaire survey performed indicated that the pediatric staff had little understanding of Hg pollution and that appropriate disposal techniques were not always used after Hg leakage. TGM concentrations in the pediatric ward and urine Hg (UHg) concentrations for the pediatric staff were 25.7 and 22.2 % lower, respectively, after the Hg pollution control measures had been implemented than before, which indicated that the control measures were effective. However, TGM concentrations in the pediatric ward remained significantly higher than background concentrations and UHg concentrations for the pediatric staff were remained significantly higher than the concentrations in control group, indicating continued existence of certain Hg pollution.

Keywords Pediatric ward · Atmospheric mercury · Urine mercury · Mercury pollution control · Impact

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Introduction

Mercury (Hg) is a global threat to environment and human health [1]. Hg can cause significant adverse effects on human health, but its toxicity depends on its chemical form [2]. The inhalation of Hg vapor emitted by dental amalgam and the ingestion of methylmercury (MeHg) in fish are the most important Hg exposure routes for the general population [2]. The MeHg contamination in fish is a worldwide concern, because fish contain high-quality protein and other essential nutrients that offer with known health benefits to humans [3]. However, the inhalation of Hg vapor is the most important occupational route (especially for people working in such settings as chlor-alkali plants, Hg mines, the Hg-based gold extraction industry, the Hg processing and sales industries, thermometer factories, and dental clinics).

About 80 % of inhaled Hg vapor can be retained in the blood and then distributed to tissues around the body [4]. Hg is principally eliminated from the body in urine and feces and the half-life for urine Hg (UHg) is about 2 months [4] (WHO 1991). Measurements of UHg are widely used for assessment of inorganic Hg (IHg) exposure in humans [5, 6]. Exposure to IHg may cause a variety of adverse effects, while the specific symptoms are found in the central nervous system and the kidney [4, 7, 8].

Anthropogenic Hg emissions and the transport and transformation of Hg in the environments are widely studied and lots of concerns were got to reduce global Hg pollution [1]. About 500–800 t of anthropogenic Hg (25–40 % of the total amount of Hg emitted globally) emitted in China each year [9]. The main Hg emission sectors in China are coal combustion, non-ferrous metal smelting, cement production, and iron and steel production [1]. China is the biggest Hg consumer over the world, 1038 t of Hg being used in 2007 [10]. Of the Hg consumed in China, most (58 % in 2007) is intentionally

used in the PVC production [10]. Other major uses of Hg are in manufacture of thermometer, sphygmomanometers, batteries, and fluorescent lamps [10]. Medical Hg uses in China in 2007 included 80 t in sphygmomanometers, 128 t in thermometers, and 6 t in dental amalgam [10].

Hg and Hg-containing products are used in a wide range of hospital and clinic settings. Hg is found in thermometers, sphygmomanometers, dental amalgam, esophageal dilators, medical batteries, and laboratory chemicals. Hg spillages often occur in hospitals. A total of 406 Hg spillage events in the USA were recorded on the US Hazardous Substances Emergency Events Surveillance between 1993 and 1998, and most of these spillages occurred in schools and universities, private residences, and health care facilities [11]. It has been estimated that 1150 to 1500 g (1.38 g per bed) of Hg are emitted from sphygmomanometers and 840 to 1398 g (1.22 g per bed) of Hg are emitted from thermometers in a hospital in Beijing each year [12]. There is a widespread concern about human exposure to Hg released from dental amalgam and Hg pollution in the atmosphere and about the adverse health effects caused by exposure to Hg from these sources [13–16].

Pediatric wards in hospitals use large numbers of thermometer containing Hg, because a child's temperature is one of the most important health indexes. The frequent use of thermometers and sphygmomanometers increases the probability of Hg spills, but related environmental pollution and health risks are often ignored. This study was designed to allow atmospheric Hg pollution in a pediatric ward and occupational exposure in staff working in the ward to be assessed and to allow the effects of implementing pollution control measures to be assessed over a period of 1 year.

Materials and Methods

Site and Subjects

The pediatric ward of a hospital was selected for this study. The ward had 40 beds and 40 full-time employees. Nine doctors and 22 nurses participated in this survey. A control group of 26 healthy Guiyang City residents with no obvious indications of Hg exposure was also selected. All of the participants signed a consent form, and ethics approval for this study was provided by the Institute of Geochemistry, Chinese Academy of Sciences.

A modified version of the questionnaire used by Pei et al. [17] was completed by each pediatric staff. The questionnaire was divided into three parts: general information, understanding of Hg pollution and risks posed to humans and the environment by Hg, and disposal methods to be used after Hg leakage.

Pollution Control Measures

The pediatric staffs were informed about Hg pollution and the toxicity of Hg in a series of lectures and were encouraged to use the electronic thermometer and sphygmomanometer. The pediatric staffs were then trained to operate temperature and blood pressure measurements in ways. For instance, make the cover with right deviation 45° to reflux the Hg liquid back to the tank and close the switch after determination; advise the patients to prevent crushing of thermometer during the temperature measurement. It can cut off Hg emissions from the source and minimize the health risks caused by occupational exposure to Hg vapor. The pediatric staffs were then trained in how to dispose of Hg, following a standard operating procedure, in an emergency after a leakage.

Atmospheric Hg and Hg Exposure

Total gaseous mercury (TGM) concentrations at different sites of the pediatric ward were measured before (in November 2012) and after (in October 2013) Hg pollution control measures had been implemented. TGM concentrations were measured in situ using a portable atomic absorption spectrometer with Zeeman background correction (Lumex RA-915+, Russia). The detection limit of the instrument was as low as 2 ng/m^3, and the instrument could perform real-time analysis with a response time of 1 s. A single data point represented an average value of a time interval of 10 s, and the measurements were performed at each sampling site for at least 10 min.

Urine samples of the pediatric staff were collected to assess Hg vapor exposure. Morning urine samples were collected in clean plastic centrifuge tubes, which were then hermetically sealed and kept frozen at 4 °C until analysis. Urine samples were digested in a water bath (95 °C) with a fresh mixture of HNO_3/H_2SO_4 (*v*/*v* 4:1) for UHg analysis. UHg concentrations in the digests were determined by BrCl oxidation, $SnCl_2$ reduction, purge, gold trap, and cold vapor atomic fluorescence spectrometry [18].

Hair samples were cut with stainless steel scissors from the occipital region of the scalp of each participant. The hair samples were then bundled together sealed in a labeled polyethylene bag and transferred to the laboratory. The portion of hair within 0–3 cm from the scalp was selected for total Hg (THg) analysis. This part of the hair was assumed to reflect the past 3 months' exposure, since the growth rate of hair was estimated to be 1 cm per month [19]. Hair samples were washed with nonionic detergent, distilled water, and acetone as described by Li et al. [20] and then dried overnight in an oven at 60 °C. The THg concentrations in the hair samples were determined by the RA-915+ Zeeman Atomic Absorption Spectrometry coupled with a PYRO-915+ thermal decomposition attachment (Lumex, Russia).

Quality Control

Quality control was consisted of method blanks, blank spikes, matrix spikes, certified reference material (CRM), and blind duplicates. The limits of determination (LOD) were 0.2 ng/L for the UHg and 0.02 μg/g for THg in hair. The average UHg concentration found in ZK020-2 was 45±4.0 μg/L (n=5), which agreed well with the certified value (49±4.2 μg/L). The mean THg concentration found in the certified hair reference material (GBW09101b) was 1.05±0.03 μg/g (n=8), which was consistent with the certified value (1.06± 0.28 μg/g). The relative differences between THg concentrations in hair and UHg concentrations in duplicate samples were <10 %.

Statistical Methods

The data were analyzed by IBM SPSS 19 for Windows software. Each dataset was tested to determine if it followed a normal distribution using the Kolmogorov-Smirnov test. If a dataset was not normally distributed, the data were normalized before further statistical analysis was performed. The data were presented as the mean ± standard deviation (SD). The effects of different factors on the UHg concentrations for the pediatric staff were compared using an independent t test. The results of the statistical tests were considered to be statistically significant when $p<0.05$.

Results and Discussion

Understanding of Hg Pollution

The average accuracy at which the participants recognized hazards caused by Hg pollution was 77 %, but the participants very poorly recognized at hazards caused by MeHg. About 71 % of the pediatric staff had experienced breaking of thermometers or Hg spills from sphygmomanometers. The percentage of staff who knew how to correctly deal with a broken thermometer was 61 %, but the percentage of staff who knew how to correctly deal with Hg leaking from a sphygmomanometer was only 32 %. These data suggested that the understanding of on Hg pollution in the pediatric staff and appropriate methods for dealing with Hg spills was inadequate.

Electronic thermometers have replaced the traditional Hg thermometers in Western countries and electronic blood pressure meters and other alternative products have also become available. The European Union has already decided to ban the use of Hg thermometers. The Minamata Convention on Mercury was ratified by delegates from 140 countries on 19 January 2013, and it is expected that this agreement will limit Hg use and emissions internationally over the next few decades. Electronic thermometers and sphygmomanometers are not popular in China because of economic reason and measurement precision. It is likely that the Hg thermometers and sphygmomanometers will continue to be the main measurement equipment in Chinese hospitals and families for a long time. It is therefore very important to educate the medical staff and the general public about Hg pollution, Hg toxicity, and appropriate methods of disposing Hg.

Atmospheric Hg

Atmospheric Hg concentrations at different sites of the pediatric ward before and after Hg pollution control measures had been implemented are shown in Fig. 1. The mean concentration was 6.8 ng/m^3 at the control site, and this represented the background of Guiyang City and was comparable with concentrations found in previous study (8.4 ng/m^3) [21]. The mean TGM concentrations at nursing station, dispensary room, treatment room, ward 1, ward 2, and doctors' office were 1004, 798, 733, 1154, 1457, and 723 ng/m^3, respectively, and were approximately two orders of magnitude higher than the concentrations found at the control site. The results showed that the pediatric ward suffered from serious airborne Hg pollution. Tiny beads of Hg were found in the corners and drawers in the nursing station. These were confirmed, through communication with the nurse on duty, to come from Hg spills from sphygmomanometers. The mean TGM concentrations in the ambient air at nurses' dressing room, aisle, and balcony were 272, 449, and 26 ng/m^3, respectively, suggesting that these regions were also affected by Hg pollution. However, the TGM concentrations in the pediatric ward were much lower than the Chinese occupational criterion (20 μg/m^3, as specified in standard GB16227-1996) [22] and the mercury

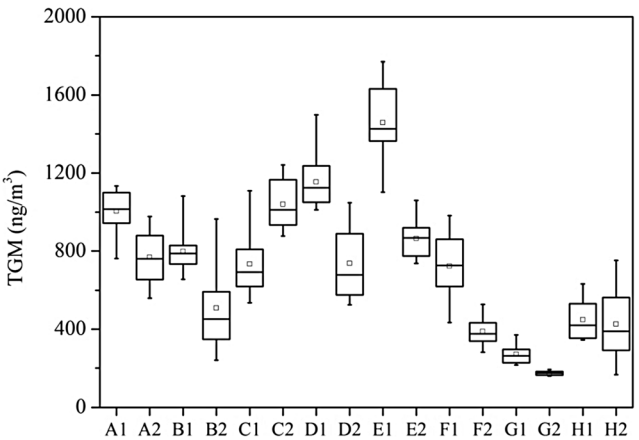

Fig. 1 Comparison of TGM concentrations at different sites of the pediatric ward before (ending "1") and after (ending "2") Hg pollution controls. *Each box* represents interquartile range (25th and 75th percentile), the *band near the middle of the box* is the 50th percentile (the median), and the *whisker* represents 5th and 95th percentile. *A*, nurse station; *B*, dispensary room; *C*, treatment room; *D*, ward 1; *E*, ward 2; *F*, doctors' office; *G*, nurse dressing room; *H*, aisle

vapor threshold limit (25 μg/m^3) [23]. Nevertheless, the TGM concentrations in the ambient air at most of the sites were higher than the national annual limit for ambient air (50 ng/m^3, as specified in standard GB3095-2012) [24] and the reference concentration (300 ng/m^3) recommended by the US Environmental Protection Agency [25].

High TGM concentrations were also found in a hospital in a previous study, mean values of 0.15, 0.17, and 0.20 μg/m^3 being found in patient rooms, nurses' areas, and other types of rooms, respectively [26]. The concentrations that were found in this study were much higher than the concentrations found in the study by Prokopowicz and Mniszek [26], indicating that the studied hospital suffered from serious airborne Hg pollution.

The TGM concentrations were still relatively high after the pollution control measures had been implemented. The mean of TGM concentrations at nursing station, treatment room, dispensary room, ward 1, ward 2, and doctors' office were 767, 508, 1040, 737, 864, and 388 ng/m^3, respectively. These concentrations were still two orders of magnitude higher than that at the control site (4.1 ng/m^3). The results showed that the pediatric ward still suffered from serious atmospheric Hg pollution after the Hg control measures had been implemented. However, implementing the control measures caused the TGM concentrations in most areas of the pediatric ward to decrease significantly (Fig. 1). The mean decrease was 25.7 %, showing that Hg pollution controls did have an effect on the TGM concentrations. However, its special physical properties mean that Hg is very easily to form small beads that can remain in the gaps of tables and floors. The large relative surface areas of small beads mean that Hg in such situations can relatively easily evaporate to produce secondary pollution, and it is very difficult to clean up the sources of the Hg pollution. Strong purging methods (such as fumigation with iodine vapor) needed to be used to completely remove historical sources of Hg pollution.

Occupational Hg Exposure

The UHg concentrations in the pediatric staff before and after pollution control measures were implemented, and the control groups are shown in Fig. 2. Before the controls were implemented, the mean UHg concentration for the pediatric staff was 1.58±1.75 μg/L, which was significantly higher (p<0.001) than that for control group (0.70±0.30 μg/L). The highest UHg concentration in the pediatric staff was 8.69 μg/L. Generally, UHg for the general population should not exceed 5 μg/L [27], and the results indicated that the pediatric staffs were exposed to Hg vapor. The inhalation of Hg-polluted air in the pediatric ward could have caused relatively high UHg concentrations for the pediatric staff.

The effects of occupation, use of skin-lightening products, hair dyeing, and dental amalgam on UHg concentrations for the pediatric staff were evaluated to allow the interference of possible factors to be excluded. Occupation, use of skin-lightening products, hair dye, and dental amalgam had no effects on the UHg concentrations (Table 1), which indicated that inhalation of Hg vapor was the main pathway of IHg exposure in the pediatric staff.

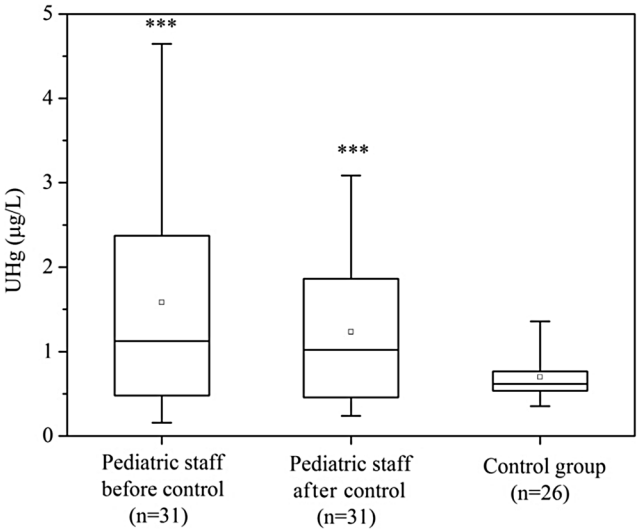

Fig. 2 Comparison of UHg concentrations for the pediatric staff before and after Hg pollution controls and the control group. ***p<0.001, compared with the control group

For hair THg concentrations, the mean hair THg concentrations for the pediatric staff and control group were 0.38±0.19 and 0.50±0.19 μg/g, respectively, and there was no significant difference between the concentrations for the two groups (p>0.05). Hair THg concentration is considered to be a good biomarker of MeHg exposure, and the results indicated that there were no obvious MeHg exposures in the pediatric staff.

Comparisons of UHg concentrations for the pediatric staff before and after Hg pollution control measures were implemented and the control groups are shown in Fig. 2. The mean UHg concentration for the pediatric staff decreased to 1.23±0.83 μg/L after the Hg pollution controls, and this was 22.2 %

Table 1 Effects of different factors on the UHg concentrations for the pediatric staff before pollution controls (mean±SD)

Factor	UHg concentrations (μg/L)	
Occupation	Doctors (n=9)	Nurses (n=22)
	1.77±1.30	1.50±1.92
Use of skin-lightening products	Yes (n=13)	No (n=18)
	2.03±1.38	1.25±1.94
Hair dyeing	Yes (n=23)	No (n=8)
	1.70±1.97	1.23±0.82
Presence of dental amalgam	Yes (n=5)	No (n=26)
	2.17±1.74	1.47±1.76

lower than the mean UHg concentration before the Hg pollution controls. The percentage of decreasing in the mean UHg concentration was similar to the decreases that were found in the TGM concentrations in ambient air through implementing the Hg pollution control measures (25.7 %). The highest UHg concentration for the pediatric staff had decreased to 3.08 μg/L after the pollution control measures had been implemented, suggesting that the Hg pollution control measures had been effective in decreasing occupational exposure to Hg in the pediatric ward. However, there was no significant difference between the UHg concentrations for the pediatric staff before and after Hg pollution controls (p=0.129). The UHg concentrations for the pediatric staff after the Hg pollution controls were still significantly higher than the UHg concentrations for the control group (p<0.001). This suggested that there still existed Hg vapor exposure in the pediatric staff after the Hg pollution controls. More rigorous cleaning activities will therefore be needed to decrease the health risks posed by occupational Hg exposure in the pediatric ward.

Conclusions

The results indicated that the ambient air in the pediatric ward was affected by Hg pollution, and that the ward staff were occupationally exposed to Hg. Implementing Hg pollution controls significantly decreased atmospheric Hg concentrations in the pediatric ward and UHg concentrations for the pediatric staff, by 25.7 and 22.2 %, respectively, on average. However, serious atmospheric Hg pollution and occupational exposure to Hg vapor remained even after the Hg pollution control measures had been implemented. Traditional Hg thermometers and sphygmomanometers therefore should be replaced with electronic instruments, and more rigorous cleaning procedures will be needed to decrease Hg pollution in the pediatric ward further.

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