Bull. Environ. Contam. Toxicol. (2005) 74:184–189

DOI: 10.1007/s00128-004-0566-y

Bulletin of Environmental Contamination and Toxicology

Trace Metals in Mosquito Coil Smoke

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Received: 30 July 2004/Accepted: 30 September 2004

The health effects related to exposure to mosquito coil smoke have been attracting more attention recently (Liu et al., 2003). The treatment of mosquito coil indoor can effectively prevent mosquitoes; therefore, burning mosquito coil commonly occurs in tropic and subtropical areas including Asia, Africa and South America. In Taiwan, mosquito coil is still widely used for fumigating mosquitoes (TEPA, 2002), and the proportion of families burning mosquito coil is approximately 45% in southern Taiwan (Yang et al., 1997). Besides the active ingredients such as pyrethrium or synthetic pyrethroid which is about 0.2% ~ 0.4% of mosquito coils (Chang and Lin, 1997; Lukwa and Chandiwana, 1998), the major constituent of mosquito coil includes wood dust or coconut shell flour etc. (Lin and Lee, 1997; Liu et al., 1988). The chemicals found in mosquito smoke are very complex (Liu et al., 1987). Epidemiological studies show an increase of the prevalence of asthma, persistent wheeze and cough in children owing to long-term mosquito coil smoke exposure (Azizi and Henry, 1991; Koo and Ho, 1994; Yang et al., 1997). In addition, this practice is a significant risk factor to epidermoid carcinoma and adenocarcinoma in lung as well (Chen et al., 1990).

While most investigations of health effects resulting from exposure to mosquito coil smoke have been focusing on organic compounds and particulate matter (Lin and Lee, 1997; Liu et al., 2003; Liu and Sun, 1988; Liu et al., 1989; TEPA, 2002); it's noteworthy that trace metals (i.e. Cd, Cr, Pb) contained in mosquito coil can be released into the environment during combustion process (Liu et al., 1987). In addition, the lead level in childrens' blood could elevate significantly as a result of hand-to-mouth activities and deposition of lead particles emitted from the burning process (ATSDR, 1999; US EPA, 1998; IPCS, 1995). This phenomenon implies that toxic metals in mosquito coil smoke may be of great concern in the public health protection. However, very few researches study the potential health effects because of the exposure to toxic metals from mosquito coil combustion. This study aims to evaluate the concentration of trace metals in mosquito coil smoke and their potential health risk relating to its practice in Taiwan.

MATERIALS AND METHODS

Three brands of mosquito coil were chosen for this study because they are the

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most popular in Taiwan. They were all manufactured, and routinely burned indoors, in Taiwan. The experimental system consisted of a combustion chamber made of polypropylene (60 x 60 x 60 cm), fresh air supply unit and moisture production unit as well as sample collection units. Before being introduced into the combustion chamber, the air was pumped through prepurifying tubes containing charcoal or molecular sieve in order to provide uncontaminated air for experiments. The moisture production unit was utilized to maintain the relative humidity of testing atmosphere. The airflow was controlled at 9000 ± 500 mL/min by adjusting needle valves. The relative humidity was monitored by a sensor (Cole-Parmer 37950-12), and was set to be 70 ~ 88 % which was similar to the ambient condition in Taiwan. The temperature of combustion chamber during mosquito coil burning was approximately 38 °C, which was about 5 to 10 °C above ambient temperature. The trace metals were collected by a 37-mm cassette with cellulose ester membrane filter at a steady state for 120 minutes with a sampling rate of 1000 mL/min. The filters were dissolved by approximately 10 mL of heated concentrated nitric acid for 10 minutes and then the solutions were diluted to 25 mL. Three blanks were processed according to the same procedure as the samples except no mosquito coil burning. This provided compensation for any possible contamination. All samples were analyzed three times by using a Perkin-Elmer Elan 5000 Inductively Coupled Plasma – Mass Spectrometer (ICP-MS). The operation conditions were as follows: 1) Carrier gas (argon, 99.999%): 0.8 L/min; 2) Plasma gas (argon, 99.999%): 15 L/min; 3) Auxiliary gas (argon, 99.999%): 0.8 L/min; 4) Pump rate: 1.5 mL/min; 5) Power: 1055 KW. The limits of detection of Cr, Mn, Co, Ni, Cd, Tl, and Pb were 39.4, 0.48, 0.12, 8.7, 125.6, 1.4, and 19.5 μg/L, respectively.

RESULTS AND DISCUSSION

The average emission rates of Cr, Mn, Co, Ni, Cd, Tl, and Pb resulting from mosquito coil combustion in the test chamber are 13.41 ± 7.88, 1.64 ± 1.84, 0.12 ± 0.07, 5.24 ± 2.64, 0.1 ± 0.08, 0.02 ± 0.02, and 1.72 ± 1.24 μg/hour, respectively (Table 1). The correlation (R^2) between these metals in mosquito coil smoke is calculated using a simple linear regression model and presented in Table 2. The relationship between Cr and Co, Cr and Ni, Cd and Tl, Cd and Tl are significant ($p < 0.05$). Compared with other daily routinely activities such as worship (Lin and Shen, 1997; Lin et al., 1997), the results suggest that exposure to heavy metals emitted from mosquito coil combustion is significant and should not be neglected; in particular, the practice period of mosquito coil (usually > 8 hours) is much longer than that of candles and Chinese joss sticks.

The levels of these metals in rooms may be estimated by their emission rates using the following equation:

$$C_t = \frac{G - (G - QC_0)e^{-\frac{Q(t-t_0)}{V}}}{Q}, \qquad (1)$$

where G is the emission rate, Q the ventilation rate, V the room volume, C_0 the

Table 1. Trace metal emission rates from mosquito coil combustion (μg/hour)

Sample ID	Cr	Mn	Co	Ni	Cd	Tl	Pb
p102501	3.16	0.65	0.03	2.22	0.11	0.02	1.12
p102502	4.97	0.21	0.06	2.08	0.05	0.02	0.45
p102503	18.10	1.24	0.18	7.51	0.05	0.01	0.80
p102504	20.54	3.73	0.15	8.37	0.00	0.00	1.44
p102601	19.04	0.46	0.22	5.90	0.17	0.03	3.26
p102602	20.80	4.78	0.11	7.21	0.24	0.05	3.66
p102603	7.29	0.41	0.10	3.38	0.09	0.01	1.34
average	13.41	1.64	0.12	5.24	0.10	0.02	1.72
standard deviation	7.88	1.84	0.07	2.64	0.08	0.02	1.24
n	7	7	7	7	7	7	7

Table 2. Correlation between trace metals in mosquito coil smoke

	Cr	Mn	Co	Ni	Cd	Tl	Pb
Cr		0.47	0.65*	0.93*	0.08	0.04	0.34
Mn	0.47		0.02	0.51	0.08	0.16	0.26
Co	0.65*	0.02		0.53	0.01	0.01	0.21
Ni	0.93*	0.51	0.53		0.001	0.001	0.18
Cd	0.08	0.08	0.01	0.001		0.86*	0.71*
Tl	0.04	0.16	0.01	0.001	0.86*		0.53
Pb	0.34	0.26	0.21	0.18	0.71*	0.53	

*: significance ($P < 0.05$)

concentration at time t_0, and C_t the concentration at time t. The typical air exchange rate (AER) for homes varies from 0.25 to 0.5 turnover/hour (Traynor et al., 1987; Tu and Knutson, 1988; US EPA, 1999). Considering that one may burn mosquito coil in the bedroom overnight, the fluctuation of concentrations of Cr, Co, Ni, Cu, Zn, Cd, Tl, and Pb, at varying air exchange rates, can be simulated by using equation (1). Assuming the initial concentrations of these metals are zone indoor, the estimated maximum concentrations of these metals in a 60 m^3 volume room after 8 hour burning of mosquito coil, at AER 0, 0.25, 0.5 and 1 respectively, are shown in Table 3.

The major health effects of cadmium poisoning are observed in the lungs, kidneys, and bones (Fergusson, 1990). Exposure to high levels of cadmium oxide fumes will result in tracheobronchitis, pneumonitis, and pulmonary edema (Donkin et al., 2000). Inhalation of cadmium chloride may elevate the frequency of lung tumors (Donkin et al., 2000). In fact, Cd and its compounds are demonstrated to cause cancer in animals (Costa, 2000) and thus are classified as

Group 1 human carcinigen by IARD (1993). However, its concinogenicity in human is not well defined yet (Costa, 2000). Our estimation of Cd shows a level of ten times higher than the typical observation in rural areas (Friberg et al., 1979), but much less that the threshold limit value (TLV) for respirable Cd (ACGIH, 1999).

Table 3. Estimated maximum concentrations (ng/m^3) of trace metals in a 60 m^3 room at AER = 0, 0.25, 0.5 and 1

	AER = 0	AER = 0.25	AER = 0.5	AER = 1
Cr	1788	1759	1730	1674
Mn	218.7	215	212	204.7
Co	16.0	15.7	15.5	14.98
Ni	698.7	687	676	654.1
Cd	13.55	13.3	13.1	12.68
Tl	2.773	2.73	2.68	2.596
Pb	229.3	226	222	214.7

Thallium is extremely toxic to human beings (Mulkey et al., 1993; Manzo et al., 1989; Zitko, 1975). The symptoms of chronic thallium poisoning are gastroenteritis, diarrhea or constipation, vomiting, and abdominal pain (ATSDR, 1992). Our results show that the level of Tl in air can be elevated 100–1000 times higher than those typical observations in the States (ATSDR, 1992); However, its health risk seems insignificant.

The health effects with regards to exposure to nickel compounds are dermatoses, asthma, hypertrophic rhinitis, nasal sinusitis, etc. (Costa, 2000). Nickel compounds are also classified as Group 1 carcinogens (IARC, 1990); the unit risk is determined to be 4.8 x 10^{-4} per ($\mu g/m^3$) (IRIS, 1996). The minimum risk level (MRL) for chronic-duration inhalation is suggested as 2 x 10^{-4} mg Nickel/m^3 by ATSDR (1997). The results indicate that exposure to Ni from mosquito coil smoke will significantly exceed the MRL in Taiwan and the potential cancer risk may be as high as 3.0 x 10^{-4}.

The occupational exposure to chromium trioxide vapors may cause an increase of the incidence of coughing, expectoration, nasal irritation, sneezing, rhinorrhea, and nose-bleed (ATSDR, 1993). The unit risk of 1.2 x 10^{-2} per ($\mu g/m^3$) for respiratory cancers for Cr(VI) is defined by US EPA (1984). Based on our estimate, the risk owing to Cr exposure could be as great as 2.0 x 10^{-2}, assuming the species of chromium in mosquito coil smoke is Cr(VI). Results clearly indicate that mosquito coil burning would put people at great risk of toxic exposure to toxic metals such as Cr and Ni. Our data suggests the need for a detailed exposure and health risk assessment of toxic metals and their chemical species, with regard to the use of mosquito coils, in order to protect the public health.

REFERENCES

ACGIH (1999) TLVs and BEIs, Cincinnati, American Conference of Governmental Industrial Hygienists.

Azizi BHO, Henry RL (1991) The effects of indoor environmental factors on respiratory illness in primary school children in Kuala Lumpur. Int J Epidemiol 20:144-150.

ATSDR (1999) Toxicological profile for lead. Agency for Toxic Substances and Disease Registry. Atlanta, Georgia.

ATSDR (1997) Toxicological profile for nickel. Agency for Toxic Substances and Disease Registry. Atlanta, Georgia.

ATSDR (1993) Toxicological profile for chromium. Agency for Toxic Substances and Disease Registry. Atlanta, Georgia.

ATSDR (1992) Toxicological profile for thallium. Agency for Toxic Substances and Disease Registry. Atlanta, Georgia.

Chang JY, Lin JM (1998) Aliphatic aldehydes and allethrin in mosquito-coil smoke. Chemosphere 36:617-624.

Chen CJ, Wu HS, Chang AS, Luh KT, Chao HH, Chen KY, Chen SG, Lai GM, Huang HH, Lee HH (1990) Epidemiology characterics and multiple risk factors of lung cancer in Taiwan. Anticancer Res 10: 971-976.

Costa M (2000) Trace elements: aluminum, arsenic, cadmium, and nickel. In: Lippmann M (ed) Environmental Toxicants-Human exposures and their health effects. John Wiley & Sons, Inc. New York. P811.

Donkin SG, Ohlson DL, Teaf CM (2000) Properties and effects of metals. In: Williams PL, James RC, Roberts RC (ed) Principles of Toxicology. John Wiley & Sons, Inc., New York. P325.

Fergusson JE (1990) The heavy elements. Pergamon Press, Oxford.

Friberg l, Kjellstrom T, Nordberg G, Piscator M (1979) Cadmium. In:"Handbook on the toxicology of metals". Ed. By Friberg L, Nordberg GF, Vouk VB. Elservier, New York, P355-381.

Koo LCL, Ho JHC (1994) Mosquito coil smoke and respiratory health among Hong-Kong Chinese epidemiological studies. Indoor Environ 3:304-310.

IARC (1993 IARC monographs on the evaluation of carcinogenic risks to humans. Volume 58: cadmium and cadmium compounds. Lyon, France: International Agency for Research on Cancer, World Health Organization. 119-237.

IARC (1990) IARC monographs on the evaluation of carcinogenic risks to humans. Volume 49: Chromium, nickel and welding. Lyon, France: International Agency for Research on Cancer, World Health Organization. 257-445.

IPCS (1995) Environmental health criteria 165: inorganic lead. International program on chemical safety. Geneva: World Health Organization.

IRIS (1996) Integrated Risk Information System. Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, U.S. Environmental Protection Agency, Cincinnati, OH.

Lin JM, Lee JK (1997) Vapor phase and particulate bound polycyclic aromatic hydrocarbons in the smoke of mosquito coils. Bull Environ Contam Toxicol

59:868-874.
Lin TS, Shen FM (2003) Trace metals in Chinese joss stick smoke. Bull Environ Contam Toxicol 71:135-141.
Lin TS, Shen FM, Chen JL, Yang MH (2003) Trace metals in candle smoke. Bull Environ Contam Toxicol 70:182-187.
Liu W, Zhang J, Hashim JH, Jalaudin J, Hashim Z, Goldstein BD (2003) Mosquito coil emissions and health implication. Environ Health Perspect 111:1454-1460.
Liu WK, Wong MH (1987) Toxic effects of mosquito coil smoke on rats. Toxicol Lett 39:231-239.
Liu WK, Sun SE (1988) Ultrastructural changes of tracheal epithelium and alveolar macrophages of rats exposed to mosquito coil smoke. Toxicol Lett 41:145-157.
Lukwa N, Changdiwana SK (1998) Efficiency of mosquito coils containing 0.3% and 0.4% pyrethrins against *An. gambiae* sensulato mosquitoes. Central African J Med 44:1104-107.
Manzo L, Sabbion E (1989) Thallium. In: Seiler HG, Sigel H (ed) Handbook on Toxicity of Inorganic Compounds, Chapter 62 Marcel Dekker Inc., New York
Mulkey JP, Oehme W (1993) A review of thallium toxicity. Vet Hum Toxicol 35: 445-453.
TEPA (2002) The residue and health risk of pesticide in residences. Taiwan Environmental Protection Agency. Taipei. (EPA-91-UIJI-03-113) (In Chinese).
Traynor CW, Apte MG, Carruthers AR, Dillworth JF, Grimsrud DT, Gundel LA (1987) Indoor air pollution due to emissions from wood-burning stoves. Environ Sci Technol 21: 691-697.
Tu KW, Knutson EO (1988) Indoor outdoor aerosol measurements for two residential buildings in New Jersey. Aerosol Sci Technol 9: 71-82.
US EPA (1984) Health assessment document for chromium. EPA 600/8- 83-014F. Research Triangle Park, North Carolina.
Yang CY, Chiu JF, Cheng MF, Lin MC (1997) Effects of indoor environmental factors on respiratory health of children in a subtropical climate. Environ Res 75:49-55.
US EPA (1999) Exposure Factors Handbook. Office of Research and Development, National Center for Environmental Assessment, U.S. Environmental Protection Agency. Washington DC.
US EPA (1998) Risk analysis to support standards for lead in paint, dust and soil. (http://www.epa.gov/lead/403risk.htm).
Yu MC, Garabrant DH, Huang, TB, Henderson BE (1990) Occupational and other nondietary risk factors for nasopharyngeal carcinoma in Guanzhou. China Int J Cancer 45: 1033-1039.
Zitko V (1975) Toxicity and pollution potential of thallium. Sci Total Environ 4: 185-192.