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垃圾焚化廠員工的職業暴露與其健康效應之流行病學研究

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中文摘要

台灣地區由於人口綢密及社會經濟迅速成長，造成垃圾量急速增加，前衛生署環保局規劃設置 23 座焚化廠來解決垃圾問題。垃圾焚化所排放的物質中含有多種有害空氣污染物，而垃圾焚化廠員工可能有多重的職業暴露，其對健康的影響需要更多的研究來釐清。本研究的主要目的是調查台中市都市垃圾焚化廠員工的健康情形、偵測工作場所的懸浮微粒濃度、探討員工的血液生化指數與其職業暴露之間的關係。研究方法分三部份，首先是面訪問卷調查，收集的資料有健康狀況、職業史、時間活動模式、與重要的干擾因子。第二部份是偵測工作場所懸浮微粒之濃度，將依據員工時間活動模式選擇 3~5 個地點，在不同季節偵測一週五天、共兩週。第三部份是員工健康檢查、血液生化和重金屬檢驗。本研究運用 SAS 軟體作資料分析，方法包括敘述性統計、雙因子分析、multiple linear regression。共有 122 員工參與本研究的問卷調查與健康檢查，參加率是 89.7%，依照其工作職稱與內容分為暴露組與對照組。懸浮微粒(PM_{10})濃度以飛灰處理場最高。以迴歸分析，同時控制年齡、性別、在廠工作年數、抽煙後，暴露組血液中的砷和 cadmium 濃度比對照組高，達統計上顯著的差異。血液生化的迴歸分析結果發現：暴露組比對照組有較低的收縮壓、尿酸、球蛋白等。其他的肝臟的消化脢、血脂肪、免疫球蛋白(E, G, M)等在暴露組與對照組並無顯著的差異。本研究使人們更了解垃圾焚化廠員工的健康狀況、職業暴露情形，及二者之間的相關性。

關鍵字：垃圾焚化爐、重金屬、懸浮微粒、職業暴露、流行病學

Abstract

Disposal of large quantities of municipal wastes has become a serious problem in many cities in Taiwan. There is an increasing trend in using incineration as an alternative way to solve the problem of waste management. Fourteen large-scale municipal waste incineration plants are currently operating in Taiwan, with nine more under construction or planned for the near future. Waste incineration emits many air pollutants, and incinerator workers may have multiple occupational exposures. The potential adverse effects of the exposures on incinerator workers' health are not well understood. The purpose of this epidemiological study was to investigate the occupational exposures and health status in workers of the Taichung city municipal waste incineration plant. The specific aims were to: (1) assess hepatic function, blood lipids, immune parameters, and blood levels of certain heavy metals in incinerator workers; (2) monitor ambient concentrations of particulates in the waste incineration plant; and (3) examine the association between the occupational exposures and various health outcomes in incinerator workers, controlling for confounding factors. This study had three main parts. The first part was an interview survey of health problems, occupational history, time-activity profiles, and potential confounders of all workers in the incineration plant. The second part comprised workplace air monitoring of particulates in three to five selected locations based on the time-activity profiles, five days a week for two weeks in different seasons. The third part consisted of physical examination by an occupational medicine physician and blood chemistry and heavy metal analysis. Workers were classified into two groups, exposure and control, based on their job titles. Data analysis consisted of descriptive statistics, bivariate analysis, and multiple linear regression analysis, using SAS software. In total, 122 workers participated in both questionnaire interview and physical examination, with a response rate of 89.7%. Means of several parameters were significantly different between groups, including hemoglobin, glucose, globulin, arsenic, and lead. Sixty air samples were collected 10 locations during the weeks before physical examination. Workplace ambient air concentrations of PM_{10} were higher in the fly ash handling area and the areas near the offices for maintenance departments, followed by the incinerator area. Finally, blood levels of arsenic and cadmium, respectively, were significantly higher in exposure group than in controls, adjusting for duration of employment, age, sex, and cigarette smoking. Exposure group had significantly lower systolic blood pressure, uric acid, globulin, total bilirubin in the multiple regression analysis. Hepatic enzymes, blood lipid parameters, IgE, IgG, and IgM were not significantly different between groups. Moreover, blood cadmium level was significantly associated higher levels of triglyceride, r-GT and IgE. Further studies are needed to clarify the associations between cadmium and triglyceride, r-GT and IgE, respectively, before conclusions can be made.

Keywords: waste incinerator; heavy metals; particulates; occupational exposure; epidemiologic study

Background and Significance

Disposal of large quantities of municipal wastes has become a serious problem in many cities in Taiwan. There is an increasing trend in using incineration as an alternative way to solve the problem of waste management. Fourteen large-scale municipal waste incineration plants are currently operating in Taiwan, with nine more under construction or planned for the near future.

Incinerator emissions are complex, depending on the composition of waste, design of incinerators, combustion condition, and the downstream pollution control equipment (Oppelt 1987; Sarofim and Suk 1994). Hazardous or municipal waste incineration may emit hydrogen chloride, sulfur oxides, particulate matter, nitrogen dioxide, metals, incomplete combustion byproducts, dioxins and furans (Oppelt 1987; Marty 1993). There has been substantial local opposition to the construction of waste incinerators because of concern about the potential health and environmental impact.

Epidemiological studies of the potential health effects of waste incineration have been extensively reviewed by one of the investigators (Hu and Shy 2001). The study by Gustavsson (1989) suggested excessive death from lung cancer (standardized mortality ratio, SMR = 355, 95% confidence interval (CI) = 162-675) and ischemic heart disease (SMR = 138, 95% CI = 95-193) among 176 male workers employed for at least one year at a municipal waste incinerator, compared with the national rates. Among those employed for more than 30 years or followed up for more than 40 years, there was a significant increase in death from ischemic heart disease (SMR=167 and 186, respectively). In another study (Gustavsson et al, 1993), mortality from esophageal cancer was non-significantly higher among the same cohort of 176 workers (SMR = 150, 95% CI = 4-834), but the SMR was very unstable with only one esophageal cancer death. Rapiti et al. (1997) studied mortality of a cohort of 532 males employed at two municipal incineration plants during 1962-1992. The workers had similar all-cause and all-cancer mortality and lower lung cancer risk (SMR = 55, 95% CI = 15-142), but significantly higher gastric cancer mortality, compared to the regional population. The SMR of gastric cancer was 421 (95% CI = 144-964) for those with more than 10 years since first employment and 461 (95% CI = 126 –1190) for those with more than 10 years of employment. Air concentrations from a 1978 survey showed that the organic dust levels ranged from 0.10 to 8.6 mg/mm^3.

Regarding the possible effects on lung function or renal and hepatic function, Bresnitz et al. (1992) found no significant difference in symptoms reported by 86 municipal waste incinerator workers in the high exposure group compared to the low exposure group as defined by their job title in a cross-sectional survey. Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC, and forced expiratory flow were similar for both groups after adjusting for smoking status. Mean blood or urinary levels of mercury, lead, arsenic, and cadmium were comparable between the two groups and were within the normal ranges. However, about 31% of the study cohort had significant proteinuria and the prevalence of hypertension was higher than that of the U.S. population. This study also included a 5-day environmental monitoring of particulates, silica, and metals. The air concentrations of respirable dust and silica, respectively, were below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 5.0 mg/m^3, and the maximal 8-hour time-weighted-average concentrations of metals/minerals, except lead and phosphorus, in area and personal breathing zone were under the standards of the American Conference of Governmental Industrial Hygienists (ACGIH)

and OSHA. Furthermore, the exposures to metals varied among incinerator workers of different job titles, and two workers had exposures to cadmium or nickel above the ACGIH Threshold Limit Values and the National Institute for Occupational Safety and Health Recommend Exposure Limit, respectively.

Several studies assessed body levels of certain chemicals in incinerator workers. Kurttio et al. (1998) compared the hair total mercury concentrations of five groups of subjects, including residents living near a hazardous waste incinerator, workers of the incinerator, and a reference group before and 10 years after operation of the incinerator in Finland. Median of mercury in hair was highest in the incinerator workers. Malkin et al. (1992) examined blood lead and erythrocyte protoporphyrin levels in 56 municipal incinerator workers and a control group of 25 boiler workers. The results showed that incinerator workers had a statistically significantly higher mean blood lead level (11.0 vs. 7.4 μg/dl), but a significantly lower mean erythrocyte protoporphyrin (21.0 vs. 27.9 μg/dl) than the controls. Wrbitzky et al. (1995) compared the blood/urine levels of selected metals and organic compounds among three groups of workers (waste incinerator, periphery, and management) employed in an industrial waste incineration plant. There were significantly higher blood levels of toluene, lead, and cadmium, and urine levels of arsenic and tetrachlorophenols in waste incinerator workers than the other two groups. The differences between groups were very small, although certain parameters of the workers exceeded the background levels of the general population. Kumagai et al. (2000) examined the serum dioxins and furans levels among three groups of municipal waste incinerator workers and three respective control groups in Japan. The results showed that serum concentration of 1,2,3,4,6,7,8-HpCDF were significantly higher in incinerator workers compared to controls.

Overall, these studies observed higher body levels of certain organic compounds (Angerer et al. 1992; Kumagai et al. 2000) and some heavy metals (Kurttio et al. 1998; Malkin et al. 1992; Wrbitzky et al. 1995) in incinerator workers compared to the controls. However, the relationship between exposure levels and body concentrations of these chemicals and consequent health effects of higher body levels of these chemicals in incinerator workers are not clear.

Specific Aims

The purpose of this epidemiological study was to investigate the occupational exposures and health status in workers from the Taichung city municipal waste incineration plant. The specific aims were to: (1) assess hepatic function, blood lipid parameters, and blood levels of certain heavy metals in incinerator workers; (2) monitor ambient concentrations of particulates in the waste incineration plant; and (3) examine the association between the occupational exposures and various health outcomes in incinerator workers, controlling for confounding factors.

Methods

This cross-sectional epidemiological study consisted of questionnaire survey, physical examination, and clinical blood chemistry analysis of incinerator workers and workplace air monitoring of the Taichung municipal waste incineration plant. Taichung municipal waste incineration plant burns 650-700 tons of municipal solid waste at 850-1050℃ per day and is quipped with semi-day scrubber and bag filter for treating flue gas. All full-time workers at the plant were invited to participate in the study after signing an informed consent. The

workers are employed either by the city Bureau of Environmental Protection or by a private company. The workers in the operation and maintenance departments were preliminarily classified as the exposed group and other workers as the control group. The study protocol has been proved by the Chung Shan Medical University Institutional Review Board.

All participating workers had physical examination by a physician and gave blood samples under fasting condition. Blood samples were analyzed at the Medical Center of Chung Shan Medical University. The analyses mainly include complete blood counts, alanine aminotransferase (ALT), aspartate aminotransferase (AST), and r-glutamyltranspeptidase (r-GT), total bilirubin, lactic dehydrogenase (LDH), creatine kinase, albumin, globulin, total cholesterol, triglyceride, glucose, uric acid, creatinine, urea nitrogen, hepatitis B surface antigen, immunoglobulin (Ig) G, E, M and etc. In addition, blood concentrations of four heavy metals, including mercury, lead, arsenic, and cadmium, were measured.

Information regarding workers' medical history, occupational history, time-activity profile in current position, uses of protection equipment, life style and demographics factors was collected by interview using a structured questionnaire. The questionnaire has been used in a study of other three incinerator plants and was revised for this study.

Based on the result of the time-activity profiles for all participants and consultation with the occupational hygienist in the plant, we chose the appropriate workplaces for ambient air monitoring. The environmental sampling for dusts is described as follows. PM_{10}, $PM_{2.5}$ and PM_1 particles were collected by personal environmental monitor (PEM-PM_{10} and –$PM_{2.5}$, SKC) and indoor PM_1 samplers, respectively. Personal exposure of respirable dust was evaluated by using a cyclone sampler with the quartz filter.

Data analysis started with descriptive statistics for important factors. The chi-square test or t-test was used for unadjusted comparisons of each of the health parameters, air quality, and heavy metals between two groups (exposed and control) of workers. Multiple linear regression analysis was applied to assess the association between exposure groups and each of the continuous health parameters, controlling for potential confounders. Natural logarithm or other transformation was used to enhance normality for outcomes with skewed distribution. SAS version 8.0 software (SAS Institute Inc., NC, USA) was applied for all the analyses.

Results

In total, 122 workers participated in both questionnaire interview and physical examination, with a response rate of 89.7%. Workers were classified into two groups, exposure and control, based on their job titles. The exposure group had 50 workers and the control group 72 workers. Frequencies of gender were significantly different between groups. Ninety-two percent of workers in exposure group were males, compared to 75% in controls. Duration of employment in the plant were similar for both groups (mean = 3.08 vs. 3.34 years). However, workers in the control group were significantly older than those in the exposure groups (39.4 vs. 34.9 years).

Means of several blood parameters were significantly different between groups, including hemoglobin, glucose, and globulin. Hemoglobin was higher in the exposure group than in controls, while means of glucose and globulin were lower in the control group. None

of the immune parameters was significantly different between groups. Furthermore, blood concentrations of arsenic and lead, respectively, were significantly different between groups. Arsenic was higher in exposure group, while lead was lower in exposure group. Levels of cadmium and mercury were not different between groups.

The Pearson correlation coefficients were statistically significant between several variables, including duration and glucose, age and glucose, age and total cholesterol, and age and albumin. Cadmium was significantly positively correlated with glucose, triglyceride, AST, r-GT, and IgE, and negatively correlated with HDL. Arsenic was not significantly correlated with any of the blood parameters. Correlation coefficients between duration of employment in the incineration plant and blood concentrations of mercury, lead, arsenic, and cadmium, respectively, ranged from -0.11 to 0.14 and were not statistically significant.

Sixty air samples were collected from 10 locations in the plant. Workplace ambient air concentrations of PM_{10} were higher in the fly ash handling area and the areas near the offices for maintenance departments, followed by the incinerator area. Results of the Kruskal-Wallis test showed significant differences among 10 locations.

Finally, multiple linear regression analyses was used to assessed the association between exposure group and blood levels of arsenic, lead, cadmium, and mercury, respectively, controlling for duration of employment, age, sex, and cigarette smoking. Exposure group was not significantly associated with blood levels of mercury. Arsenic level (parameter estimate (standard error, se) = 0.96 (0.28) ppb in natural logarithm scale).and cadmium level (parameter estimate (se) = 0.47 (0.17) ppb in natural logarithm scale) were significantly higher in exposure group than in controls. On the contrary, blood lead level was significantly lower in exposure group than in controls (parameter estimate (se) = -0.20 (0.05) ppb in natural logarithm scale). Results of multiple linear regression analyses for the association of each of the blood parameters and exposure group, adjusting for duration of employment, age, sex, cigarette smoking, and heavy metals, showed that the exposure group had significantly lower systolic blood pressure, uric acid, globulin, total bilirubin. Furthermore, hepatic enzymes, blood lipid parameters, IgE, IgG, and IgM were not significantly different between groups. Moreover, blood cadmium level was significantly associated higher levels of triglyceride, r-GT and IgE.

Discussion

This study investigated hepatic function, blood lipid parameters, immune function and blood levels of four heavy metals in incinerator workers and monitored ambient concentrations of particulates in the Taichung municipal waste incineration plant. Blood levels of arsenic, lead, cadmium, respectively, were significantly different between exposure and control groups, controlling for potential confounders. Moreover, blood cadmium level was significantly associated higher levels of triglyceride, r-GT and IgE, taking into account other factors. Blood lipid parameters, IgE, IgG, and IgM were not significantly different between groups.

Previous studies reported higher body levels of some heavy metals (Kurttio et al. 1998; Malkin et al. 1992; Wrbitzky et al. 1995) in incinerator workers compared to the controls. However, the relationship between exposure levels and body concentrations of these chemicals and consequent health effects of higher body levels of these chemicals in incinerator workers were not assessed in these studies. In this investigation, we observed

higher blood levels of arsenic and cadmium, but lower blood level of lead in workers of the exposure group than did workers in the control groups. Moreover, blood cadmium level was significantly associated higher levels of triglyceride, r-GT and IgE. Further studies are needed to clarify the associations between cadmium and triglyceride, r-GT and IgE, respectively, before conclusions can be made.

More incinerators are going to be functioning in Taiwan and more workers will be exposed to the by-products of waste incineration. It is important to assess the occupational exposures to heavy metals and/or other combustion byproducts and their potential health effects in incinerator workers. Results from this study provide valuable information regarding the heavy metal and particulates exposures as well as potential health effects in incinerator workers.

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