

Increased Lead Absorption Caused by Working Next to a Lead Recycling Factory

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The objective of this study was to determine whether workers at a factory in Taiwan, adjacent to lead recycling plant, were affected by lead contamination. Workers at the lead recycling plant itself were found to suffer from lead poisoning; air and soil outside the plant were heavily contaminated by lead. Forty-one of the 45 workers in a forging factory next to the lead recycling plant were enrolled as the exposed group. A comparison group of 51 workers were selected from another forging factory about 20 km away. Each subject was interviewed about his lifestyle, work history, and residence, and blood was drawn for lead measurement by graphite furnace atomic absorption spectrometry. The results showed that two groups were compatible in age, sex, and smoking patterns. Blood lead of the exposed group was significantly higher than that of the comparison group (mean \pm SD: 20.4 ± 9.4 $\mu\text{g/dl}$ vs. 5.9 ± 2.9 $\mu\text{g/dl}$). The difference was independent of sex and working zones. Blood lead levels were lower among exposed workers who had been employed less than 2 months compared with those employed longer. There was no difference among exposed workers in different outdoor working zones. Five months after improvement of pollution control and decrease in the production volume of the lead factory, 30 exposed workers were retested for blood lead. The blood lead of outdoor workers had an average decrease of 4.2 $\mu\text{g/dl}$ while that of indoor workers showed no significant difference. We concluded that the changes of blood lead levels among exposed workers were caused by lead contamination generated by the neighboring lead recycling plant. © 1994 Wiley-Liss, Inc.

Key words: environmental contamination, community lead exposure, blood lead level, lead recycling factory

INTRODUCTION

Lead was first reported to be hazardous to health as early as 200 B.C. At the beginning of this century, Dr. Alice Hamilton [1943], the pioneer of occupational lead poisoning, reported that environmental lead pollution may cause health problems. Modern studies [De la Burde and Choate, 1972; Rutter, 1983; Lippmann, 1990; Rabinowitz et al., 1992] indicate that lead is not an essential element to man, and low levels of lead, e.g., 8–15 $\mu\text{g/dl}$ in blood, may produce adverse effects in intellectual

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development. Thus, prevention of lead poisoning should not be confined to the lead-related industries, but should be extended to the community [Freudentberg and Golub, 1987].

While there have been many reports about environmental pollution by lead-related industries [Baker et al., 1977; Kaye et al., 1987; Wang et al., 1989; Vimpani et al., 1985; Baghurst et al., 1985; Morse et al., 1979], the victims were mostly confined to workers' families or residents, especially children, of nearby communities. The lead pollution in these outbreaks was spread by dust, fumes, or water. To our knowledge, few, if any, reports exist about the lead contamination spreading to nearby factories and workers.

In recent years, industrial development in Taiwan has been very rapid. The amount of lead utilization has been increasing and occupational lead poisoning is not uncommon [Soong et al., 1976; Yip et al., 1988; Jang and Wang, 1989]. In 1987, following a case of occupational poisoning in a lead battery recycling plant in northern Taiwan, we demonstrated that 85% of workers in the lead recycling plant had blood lead levels more than 40 $\mu\text{g}/\text{dl}$ and 31.2% workers more than 80 $\mu\text{g}/\text{dl}$. The average blood lead in office staff was up to 38.5 $\mu\text{g}/\text{dl}$ [Jang and Wang, 1989].

Environmental monitoring demonstrated that air and soil outside the plant were contaminated by lead. The lead concentrations in the ambient air at distances of 50 and 100 m from the lead recycling plant were 12.9 ± 11.4 and 12.8 ± 8.0 $\mu\text{g}/\text{m}^3$, respectively, during sunny days, while they were lower—1/6 or 1/10—during rainy days [Wang et al., 1992]. The lead recycling plant is located in an industrial zone, and there is an iron forging factory nearby (Fig. 1). The objective of this study was to determine whether workers at the adjacent factory were affected by fugitive lead contamination.

MATERIALS AND METHODS

Forty-one out of 45 workers of a forging factory next to a lead recycling plant were enrolled as the exposed group; 30 of them voluntarily underwent follow-up examination 5 months later. The 86 workers from another forging factory, 20 km away with no lead-related factory nearby, were asked to be the reference group; 51 (59.3%) voluntarily participated. These two forging factories had the same raw materials, manufacturing process, and products. Their raw materials contained no lead or its alloy. More than half of the workers of the exposed factory had worked in the reference factory, but they had left and set up their own company about 5 years previously. Thus, the operation of the two forging factories was comparable. After a walk through, we designed a questionnaire for this study, which contained basic demographic data, including sex, birthdate, work history, residence, transportation to and from the factory, jobs of family members, hobbies related to lead exposure, smoking, etc. Each subject was interviewed by four research assistants using standardized protocol. We defined those who stayed indoors more than half of their working time as working indoors, e.g., office staff, cook, guards, sanitary workers. Those who stayed in the semi-open plant more than half of their working time were defined as working outdoors, e.g., die making, steel cutting, forging, sand blasting, packing, quality control, and maintenance. Besides ventilation and dust exposure, the indoor and outdoor workers had different quantities and sources of drinking water. Since a smoker usually has a greater likelihood to inhale or ingest lead from a

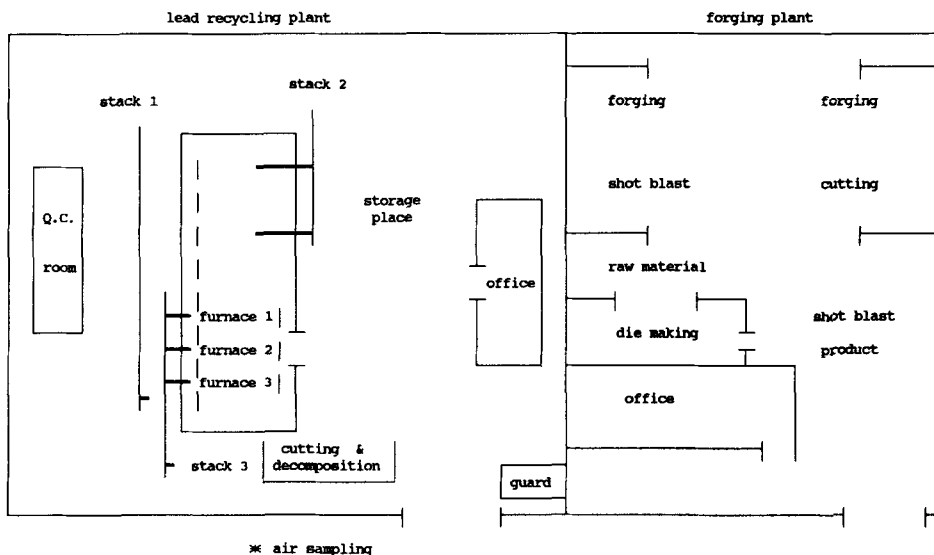


Fig. 1. Forging plant next to a lead recycling plant.

lead-contaminated workplace [Tola and Nordman, 1977], we defined those who had not abstained from smoking over the past 2 months and smoked more than one cigarette inside the plant each day as smokers.

All workers were asked to wash their antecubital area with soap and water first, and then each of them underwent venipuncture to collect 5 ml venous blood with a vacuum tube (Monoject, Sherwood Medical, USA) containing ethylenediamine tetraacetic acid as the anticoagulant. Sample pretreatment was performed under a high-efficiency particulate air filter (class 100). One hundred microliters of shaken blood sample was first added with 400 μ l of pretreatment solution containing 0.1% Triton X-100 (scintillation grade) and 1.25% ammonium dihydrogen phosphate (puratonic grade). After homogenization, it was directly introduced into a Perkin-Elmer Zeeman 5100pc through AS 60 autosampler for flameless atomic absorption spectrometry. Our laboratory has a consistent intralaboratory quality control and has participated in the blood lead proficiency test of the United States Centers for Disease Control (CDC) since 1985. The average difference (± 1 SD) of blood lead between our measurements and the CDC target values of 24 samples during 8 recent months was 1 ± 1 μ g/dl, indicating that our blood lead measurements are accurate.

Data Analysis

Since the blood lead level is an indicator of lead exposure over the past 2–3 months [Zielhuis, 1983] we defined those who worked for less than 2 months as new workers. During data analysis, the new workers and three truck drivers who were usually working off-site and had relatively little lead exposure were grouped into a separate category.

Because our subjects were few in number and the blood lead distribution was not normal, most of the comparisons were performed using nonparametric methods, such as Wilcoxon rank sum test. For the comparison of the blood lead levels between

TABLE I. Exposure Categories of Workers in Two Taiwanese Iron Forging Factories

	Exposed factory next to lead recycling plant	Reference factory 20 km distant
Total no. of workers	45	86
No. of examined workers	41 (91.1%)	51 (59.3%)
No. of new employees, and truck drivers	5	4
No. working indoors	11	11
No. working outdoors	25	36

the initial examination and 5 months later among the 30 workers at the exposed factory, a paired *t* test was used. Multiple linear regression analysis was also performed to determine significant risk factors for the initial blood lead. The independent variables included working indoors or outdoors at the exposed factory, sex, and smoking. A similar multivariate analysis was performed for the decrease in blood lead levels among workers at the exposed factory. The change in blood lead levels between the two examinations was the dependent variable; working indoors or outdoors, sex, and smoker were the independent variables. A *p* value of 0.05 was considered statistically significant.

RESULTS

We classified the subjects by exposure categories and factories (Table I). After excluding new employees and truck drivers the two groups were not different and relatively compatible for age, sex, and percentage of male smokers (Table II). None of female workers had ever smoked.

The average blood lead of the exposed group was significantly higher than that of the reference group (mean \pm SD: 20.4 \pm 9.4 μ g/dl vs. 5.9 \pm 2.9 μ g/dl). This difference persisted after stratification by sex and working indoors vs. outdoors (Table III). Blood lead levels were lower among exposed workers who were employed for less than 2 months than those employed longer, but no such difference was observed in the reference group. There was no difference in blood lead among exposed workers who worked outdoors, according to their residence area (urban vs. rural), or according to their manufacturing job. Blood lead levels were higher among outdoor workers than among indoor workers at the exposed factory. This difference persisted even after stratification by gender. At the reference factory, the blood lead levels were the same among outdoor and indoor workers, regardless of sex. Multiple linear regression showed that blood lead was significantly associated with working at the exposed factory outdoors and indoors (Table IV).

In this study, all workers at the reference factory lived near their plant, which was located in a rural area. Twenty workers from the exposed factory lived in the same village. While 2 additional workers lived in the countryside, all the other 14 workers (38.8%) of the exposed factory lived in a city or near a suburban area. Most cases of elevated blood lead (more than 15 μ g/dl) occurred among outdoor workers at the exposed factory. If we stratified them by residence as rural vs. urban, there was no difference in their blood lead. Also our survey found that none of workers had a

TABLE II. General Characteristics of Examined Iron Forging Factory Workers Excluding New Employees and Truck Drivers

	Exposed factory next to lead recycling plant	Reference factory 20 km distant
No.	36	47
Age (years)	33.0 ± 9.6	35.1 ± 11.5
Duration of work (years)	3.0 ± 1.7	6.7 ± 5.4
% Male	83.3	74.5
% Male smoker	43	57

TABLE III. Comparison of Initial Blood Lead Levels (µg/dl) of Workers in the Two Iron Forging Factories by Wilcoxon Rank Sum Test.

	Exposed factory			Reference factory		
	No. of workers	Median	Range	No. of workers	Median	Range
Working indoors (total)	11	11 ^{a,b}	21~6	11	5 ^c	5~4
Male	6	15	21~6	4	5	5~4
Female	5	11	14~9	7	4	5~4
Working outdoors (total)	25	24 ^a	49~10	36	5.5	20~4
Male	24	23	49~10	31	6	20~4
Female	1	40		5	4	5~4
New employees or truck drivers	5	8 ^d	14~3	4	6	9~5

^ap < 0.001, if compared with the reference factory.

^bp < 0.001, if compared with working outdoors.

^cp > 0.1, if compared with working outdoors and stratified by sex.

^dp = 0.003, if compared with workers employed for more than 2 months by the same factory.

TABLE IV. Results of Multiple Linear Regression Analysis of Blood Lead Levels of All Examined Forging Plant Workers*

Variable definition	Regression coefficient ± SE	p value
Intercept	5.34	
Exposed factory, indoors Yes = 1, no = 0	6.84 ± 1.96	<0.001
Exposed factory, outdoors Yes = 1, no = 0	17.6 ± 1.45	<0.001
Smoking in plant Yes = 1, no = 0	-0.73 ± 1.40	0.61
Sex Male = 1, female = 0	1.13 ± 1.74	0.52

*Multiple R² = 0.68.

part-time job or a lead-related hobby. Moreover, none of their family members currently held a lead-related job.

Five months after improvements in pollution control and decrease in production volume at the nearby lead factory, 30 of the exposed workers were retested for blood lead. The blood lead of outdoor workers had an average decrease of 4.2 µg/dl, while

TABLE V. Results of Paired t Test of Blood Lead Levels (PbB, in $\mu\text{g}/\text{dl}$) at First Examination and 5 Months Later Among Workers at a Forging Plant Adjacent to a Battery Recycling Plant

Working	No.	PbB difference			p value
		Mean \pm 1 SD	Maximum	Minimum	
Indoors	9	0.9 \pm 0.7	4	-2	0.24
Outdoors	21	4.2 \pm 1.4	26	-3	0.008

that of indoor workers showed no significant difference (Table V). Multiple linear regression analysis also showed that sex, smoking, and working outdoors per se all did not have any significant effect on the self-comparison difference of blood lead between two examinations.

DISCUSSION

We have observed that blood lead levels among workers exposed to lead emissions from an adjacent factory were higher than those of reference workers. Potential alternative lead sources, such as household activities or transportation did not affect blood lead, and therefore, we believe that exposure at their worksite was the major source of lead exposure. Further evidence supports the hypothesis that the major lead contamination at the exposed factory was fugitive dust emitted by the neighboring lead battery recycling plant.

Firstly, blood lead levels among workers of the exposed factory who were employed less than 2 months were lower than those employed longer, but a similar comparison inside the reference factory showed no difference. Secondly, our previous study showed that there was lead contamination around the lead recycling plant. Also, at the same period of this study, air concentrations of lead monitored by the local environmental protection bureau showed a range of 14–32 $\mu\text{g}/\text{m}^3$. Thirdly, all workers at the exposed factory took lunch, which was supplied by the company, in the plant and they drank from the same source of water. So, the difference in blood leads between indoor and outdoor workers could not be attributed to food or water at the workplace. Fourthly, both factories denied that their raw materials contain lead or its alloy. In the forging process, metal is heated to 1,000°C and there is an exposure of metal fume. However, the 11 workers at the exposed factory who engaged in forging did not show a higher blood lead than the other outdoor workers. So, the forging operation was not a major source of lead exposure in our study. Fifthly, indoor workers at the exposed factory had an elevated blood lead compared with indoor workers of the reference factory. And, the blood lead levels among outdoor workers at the exposed factory were higher than those working indoors. Such difference was not affected by sex or social class. Lastly, 5 months after the production of the battery recycling factory was forced to slow down, all outdoor workers at the exposed factory showed a significant decrease of blood lead. We therefore conclude that the increased blood lead levels of workers at the exposed factory were mainly due to fugitive lead dust contamination from the neighboring battery recycling plant.

Because the operation of the lead recycling plant was not completely stopped, the air monitoring by the local environmental bureau still showed a range of 0.1–9.9 $\mu\text{g}/\text{m}^3$, 5 months after our first worker examinations. Possibly because the soil or dust

on the ground floor of the exposed forging factory was not removed, we observed a decrease averaging only 4.2 $\mu\text{g}/\text{dl}$ among exposed workers, and the Spearman rank correlation coefficient between blood lead levels for the two tests was 0.93. This finding may indicate that the accumulated bone stores are an endogenous source of lead to blood, in addition to the persistent exposure from a contaminated workplace. These findings emphasize that a comprehensive control of all lead exposure sources is necessary to eliminate such a hazard.

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