

## Lead Poisoning In A Battery Recycling Smelter

Chang - Sheng Jang<sup>1</sup> Jung - Der Wang<sup>2</sup>  
Yaw - Huei Hwang<sup>3</sup> Yang - Chuan Chang<sup>4</sup>  
Puli Christian Hospital<sup>1</sup>.

National Taiwan University College of Public Health, Institute of Occupational Medicine  
and Industrial Hygiene<sup>2</sup>.

Ph.D. in Epidemiology, Department of Environmental Health, University of Cincinnati<sup>3</sup>.

Departments of Internal Medicine and Neurology, National Taiwan University Hospital<sup>4</sup>.

### Abstract

This study was undertaken to determine the prevalence risk factors and symptomatology for lead poisoning among workers in a lead - battery recycling plant located in northern Taiwan. Sixty - four (58.2%) out of 110 workers were enrolled in our study. A comprehensive medical examination including a questionnaire, neurological examination, blood lead, complete blood count (CBC), count of erythrocyte with basophilic stippling (B.S.RBC), serum creatinine, blood urea nitrogen (BUN), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and routine urine examination was performed on each worker. Blood lead levels were measured by atomic absorption spectrophotometry. The results revealed that 55 workers' blood lead levels were above 40  $\mu\text{g}/\text{dl}$ , and 31 workers were diagnosed with lead poisoning. The average blood lead level of workers whose jobs involved furnace, maintenance, and workplace cleaning (male only) were all over 80  $\mu\text{g}/\text{dl}$ , while those whose jobs involved dissecting, refining, or crane operations were between 60 and 70  $\mu\text{g}/\text{dl}$ . Even office workers and guards had blood lead levels averaging  $38.5 \pm 4.9 \mu\text{g}/\text{dl}$ . Smoking, drinking, and wearing a cotton mask were not associated with blood lead level. B.S.RBC increased with blood lead level. Either  $\text{B.S.RBC} \geq 8/1000$  or positive neurological signs has the highest diagnostic accuracy when compared with other combinations of symptoms and/or signs. We conclude that lead poisoning is a serious occupational problem in Taiwan which needs to be controlled immediately.

*Key word: Lead, Smelter, Abdominal Colic, Anemia, Basophilic Stippling, Polyneuropathy.*

## Introduction

The toxicity of lead has been known for more than a thousand years, but occupational lead poisoning still occurs sporadically in the world, especially in developing countries [1-4]. In Taiwan, in the past two decades it was reported that lead encephalopathy occurred in a lead battery factory [5], and polyneuropathy occurred in a tile glazing factory [6]. However, these cases were all relatively advanced when they were first diagnosed by doctors in large medical centers. There has been no report on the prevalence rate of increased lead absorption and/or lead poisoning in a typical lead factory in Taiwan. As prevalence rates generally affect the positive predictive value [7], it is crucial that we develop our own diagnostic criteria for the recognition of occupational lead poisoning in Taiwan.

In September 1987, a lead - battery recycling worker came to the medical clinic of the National Taiwan University Hospital (NTUH) with symptoms of anemia and bilateral wrist drop. He was diagnosed with

lead poisoning when we found that his blood lead level was  $80 \mu\text{g}/\text{dl}$ . To determine the prevalence rate of lead poisoning among workers and the diagnostic accuracies of various combinations of symptoms and signs, we conducted this study under the assistance of the Council of Labor Affairs of the Executive Yuan.

## Materials and Methods

The factory which we examined was established in 1984 and began to operate in 1985. It was located in a valley, just beside a provincial road. Batteries were imported and transported from a nearby seaport. The major process performed at the factory is the retrieval of lead from used lead batteries as shown in Fig.1. Of the 110 employees of the factory, 100 worked in the factory; of these 100 workers, 11 were females. Only 64 of the employees accepted this voluntary investigation. The entire recycling process was divided into 9 tasks to compare the degree of lead exposure among different tasks.

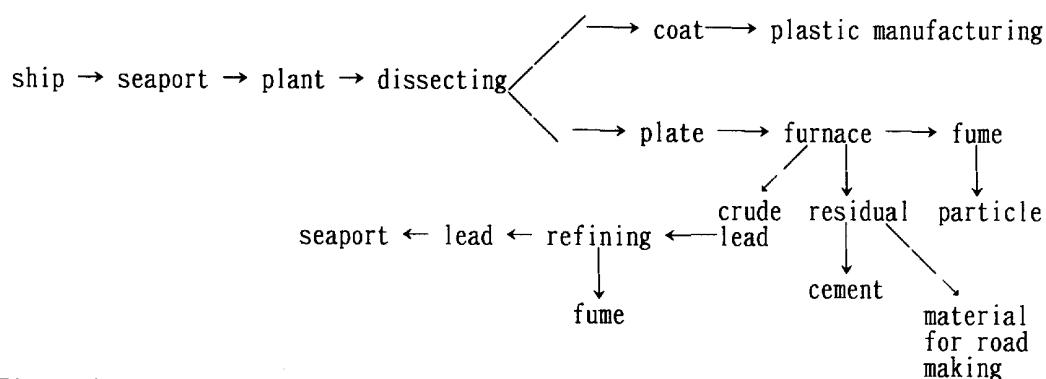


Figure 1. The Processing of Lead-battery Recycling

The survey included a questionnaire and tests of blood lead level and physiological functions. The questionnaire, which was administered individually, included personal information, disease history, use of medicine, smoking and drinking habits, complaints, occupations of family members, previous work experiences, and use of protective mask. A heparinized vacuum tube was used to collect whole blood after the skin was washed thoroughly with soap and water and rubbed with alcohol several times to avoid lead contamination through skin and air. Blood lead levels were measured within a week by flameless atomic absorption spectrophotometry (AAS) with an Instrumental Laboratory 12E AAS. We have participated in inter-laboratory quality control of blood lead measurement provided by the Center for Disease Control and Prevention in the USA since 1985.

Physiological tests including complete blood count (CBC), count of erythrocyte with basophilic stippling (B.S.RBC), alanine aminotransferase (ALT), aspartate aminotransferase (AST), blood urea nitrogen (BUN), serum creatinine and routine urine examination were conducted by the Department of Clinical Pathology of the NTUH. A neurological examination for each worker was conducted at the workplace by a boardcertified neurologist from the Neurology Department of the NTUH without any information on the workers' blood lead levels.

A subjective symptom was defined as positive if it occurred at least twice a week,

such as abdominal colic, diarrhea, constipation, etc. Hand weakness was defined as positive if a worker felt loss of muscle power in both hands and the symptom only began after he or she started to work in this factory or other similar lead factories. Anemia was defined as a hemoglobin level (Hb) of less than 12.95 g/dl in males and less than 10.97 g/dl in females [8].

Besides simple Chi-square statistics and means, we also calculated specificity, sensitivity, and positive predictive values for different combinations of symptoms and signs [7]. We employed the definition of adult lead poisoning as defined by Cullen et al. [9] - an excess of lead burden (blood lead over 40  $\mu\text{g}/\text{dl}$  or positive lead immobilization test) and measurable impairment of at least one organ system historically associated with lead exposure and without an alternative explanation after an appropriate medical workup. A multivariate linear regression analysis was also performed using the BMDP computer software [10].

## Results

We found that the distributions of sex, age, and duration of employment at each task did not differ between workers who came for medical examinations and those who did not (Table 1). Blood lead levels of workers who performed different tasks differed significantly from each other. The furnace workers, maintenance workers and male cleaners all had an average blood lead level exceeding 80  $\mu\text{g}/\text{dl}$  (Table 2). As most female workers worked as

cleaners in places of lower exposure, such as the office, it was difficult to detect any physiological effect associated with sex difference. There were 37 male workers who smoked. Of the 19 workers at the smelting furnaces, 12 were smokers and 7 were non-smokers. No effect on blood lead was noted between smokers and nonsmokers. Most workers stayed in the factory 8 hours per day, except for those who were engaged at the furnace and performed refining, these workers stayed in the factory for more than 10 hours each day. Twenty-nine workers wore cotton masks, which were usually washed or changed every day. A multivariate linear regression analysis was performed with the blood lead level as the dependent variable, and age, smoking habit, drinking, duration of employment, working hours per day, distance between residence and factory (in km), wearing mask, and the type of task as independent variables. A significant difference was found only in the type of task ( $p < 0.05$ ). Two workers had one relative each working in the same factory, and the others did not have any relatives working in the lead industry. Three furnace workers had blood lead levels exceeding  $80 \mu\text{g}/\text{dl}$  after working for only 50 days.

The bilateral weakness of extensor muscles was caused by abnormality of the extension of joint muscles of fingers, wrists, and ankles. Every case was referred to the neurologic department of the NTUH to rule out other possible causes of such a paralysis. In cases whose blood lead level was above  $80 \mu\text{g}/\text{dl}$ ,

weakness of the extensor muscles was almost always reported. One office employee was found to have weakness of extensor muscles. Further investigation revealed that he had previously worked at the furnace for 8 years. Four workers with weakness of extensor muscles had durations of employment between 50 and 100 days. Only a few employees had symptoms such as abdominal colic, diarrhea, constipation or arm weakness as summarized in Table 3. However, 5 out of the 8 workers who complained arm weakness were in the dissecting department. There were 13 male and no female employees suffering from anemia, and 12 of these 13 had worked in the smelter for more than 110 days. However, there was no linear correlation between the blood lead and hemoglobin level. All workers with blood leads under  $40 \mu\text{g}/\text{dl}$  had B.S.RBC less than  $8/1000$ , and all workers with blood leads over  $100 \mu\text{g}/\text{dl}$  had B.S.RBC more than  $8/1000$  (Table 4). When a multivariate linear regression analysis was made with the B.S.RBC as the dependent variable, and sex, age, duration of employment, and blood lead level as independent variables, a significant positive association ( $p < 0.05$ ) was found only between the B.S.RBC and the blood lead level. No significant relation was found among other variables. No abnormality was found in the routine urine examination, serum creatinine, BUN, ALT or AST. These results indicated that lead poisoning might not yet have any significant impact on the kidney and liver functions over this short duration.

Table 1. Comparison of Sex, Age, Work Tasks, and Durations of Employment among Battery Recycling Workers Who Came and did not Come for the Medical Examination, Taiwan, 1988.

Workers Character- istics tasks	examined				non-examined			
	sex		age	duration of employment days	sex		mean age	duration of employment day
	Male	Female	mean $\pm$ s.d.	mean $\pm$ s.d.	Male	Female	$\pm$ S.D.	mean $\pm$ S.D.
Furnace	19	0	37 $\pm$ 10	349 $\pm$ 328*	14	0	35 $\pm$ 5	553 $\pm$ 261
Maintenance	3	0	30 $\pm$ 4	259 $\pm$ 243*	2	0	37 $\pm$ 1	410 $\pm$ 218
Dissecting	10	0	35 $\pm$ 8	450 $\pm$ 225	14	0	36 $\pm$ 9	324 $\pm$ 306
Refining	6	0	31 $\pm$ 4	559 $\pm$ 166	3	0	29 $\pm$ 2	679 $\pm$ 311
Crane operator	6	0	44 $\pm$ 4*	544 $\pm$ 376	3	0	36 $\pm$ 4	1007 $\pm$ 838
Male cleaner	4	0	43 $\pm$ 1*	698 $\pm$ 229*	2	0	49 $\pm$ 1	133 $\pm$ 14
Female cleaner	0	6	50 $\pm$ 3	548 $\pm$ 248	0	0	—	—
Office, guard	4	1	52 $\pm$ 13	960 $\pm$ 861	4	4	43 $\pm$ 20	465 $\pm$ 336
Salesman etc.	1	4	27 $\pm$ 6	149 $\pm$ 136	0	0	—	—

Table 2. Distributions of Blood lead levels Among Battery Recycling Workers by Task.

Task	Blood lead level( $\mu$ g/dl)	No. of persons		
	mean $\pm$ S.D.	<40	40-80	>80
Furnace(熔爐)	86.9 $\pm$ 13.6	0	7	12
Dissecting(切割)	69.4 $\pm$ 16.1	1	7	2
Maintenance(維修)	82.4 $\pm$ 7.5	0	1	2
Cleaner(辦公室清潔工)	48.0 $\pm$ 5.2	0	6	0
Refining(精煉)	64.2 $\pm$ 16.1	0	5	1
Cleaner of working area (現場清潔工)	95.4 $\pm$ 35.1	0	2	2
Office(辦公室員工)	37.8 $\pm$ 4.2	4	1	0
Crane operator(推高機操作)	63.9 $\pm$ 11.1	0	5	1
Salespersons etc.(外務員)	7.9 $\pm$ 5.8	5	0	0

Table 3. Distributions of Various Symptoms and Signs Among Battery Recycling Workers by Task.

Task	paralysis of extensor muscles N(%)	Abdominal pain N(%)	Diarrhea N(%)	Constipation N(%)	Weakness of arms N(%)	Abdominal colic or disarrhea
Furnace	11(58)	3(16)	3(16)	0	2(11)	4(21)
Dissecting	5(50)	3(30)	2(20)	0	5(50)	5(50)
Maintenance	1(33)	1(33)	1(33)	1(33)	1(33)	1(33)
Cleaner	0	0	0	0	1(17)	0
Refining	0	1(17)	2(23)	1(17)	0	2(33)
Cleaner of working area	1(25)	0	0	0	0	0
Office	1(20)	0	0	1(20)	1(20)	0
Crane operator	2(33)	1(17)	2(33)	1(17)	1(17)	2(33)
Other	0	0	0	0	0	0

Table 4. Association Between Number of Red Blood Cells(RBC) with Basophilic Stippling and the Blood Content of Lead Among Battery Recycling Workers

Blood lead ( $\mu$ g/dl)	Basophilic stippling (no. per 1000 RBC)		
	0 - 3	4 - 7	$\geq 8$
0 - 19.9	4	1	0
20 - 39.9	2	2	0
40 - 59.9	7	7	1
60 - 79.9	6	9	5
80 - 99.9	2	9	4
> 100	0	0	5

Table 5. Diagnostic Accuracies of Lead Poisoning According to Symptoms and/or signs of Workers from a Lead Recycling Factory in Taiwan.(31 out of 64 workers were diagnosed as having occupational lead poisoning).

Symptom or sign	sensitivity	specificity	positive predictive value	negative predictive value
Ab	0.39	0.94	0.86	0.62
Neu	0.65	0.97	0.95	0.74
An	0.42	1.00	1.00	0.65
Ba	0.48	1.00	1.00	0.67
Ab or Neu	0.81	0.91	0.89	0.83
Ab or An	0.65	0.94	0.91	0.74
Ab or Ba	0.68	0.94	0.91	0.76
Neu or An	0.87	0.97	0.96	0.89
Neu or Ba	0.97	0.97	0.97	0.97
An or Ba	0.65	1.00	1.00	0.75
Ab and Neu	0.23	1.00	1.00	0.58
Ab and An	0.16	1.00	1.00	0.56
AB and Ba	0.19	1.00	1.00	0.57
Neu and An	0.19	1.00	1.00	0.57
Neu and Ba	0.16	1.00	1.00	0.56
An and Ba	0.26	1.00	1.00	0.59

Ab : abdominal colic or diarrhea

Neu : polyneuropathy manifested as bilateral weakness of extensor muscles.

An : anemia( $Hb < 12.95 \mu$ g/dl in male,  $Hb < 10.97$  in female)

Ba : (basophilic stippling RBC)  $\geq 8/1000$

In total, twelve had abdominal colic or diarrhea, 22 had polyneuropathy, 13 had anemia. According to the criteria proposed by Cullen et al [9], 31 workers had lead poisoning. Since we have not performed a vigorous diagnostic workup to rule out all other causes of anemia, we might be overestimating the number of cases of lead poisoning. Such an effect would be large if many female workers were suffering from anemia due to menorrhagia or other causes. However, since there were no female employees with anemia, the magnitude of such an overdiagnosis should be low. Our strict definition of gastro-intestinal involvement (more than twice per week) might result in of underdiagnosis. We combined different gastrointestinal, neurologic and hematologic symptoms and signs as possible convenient tests of occupational lead poisoning. Most had specificity and positive predictive value over 90% (Table 5). Sensitivity and negative predictive values varied with different combinations. A constant search for B. S.  $RBC \geq 8/1000$  and bilaueral weakness of extensor muscles for detecting polyneuropathy seems to have the highest yield, with specificity, sensitivity and positive values all above 95% if either one of these two signs is positive.

## Discussion

Although the distributions of sex, age, and duration of employment were generally similar between the examined and un-examined workers, furnace and maintenance workers who came for the examination had a

shorter duration of employment than those who did not come. Some workers alleged that those who did not come were afraid of losing their jobs because they were heavily exposed and might have a higher level of blood lead. Therefore, we concluded that a prevalence rate of lead poisoning of 48% might be an underestimation.

During our walk-through survey at the factory, we found that brownish red dust, which might contain a high concentration of lead, was spread throughout the grounds of the factory. This is the reason why maintenance workers and male cleaners had very high levels of blood lead. The local exhaust hood was not working well and lead fumes could usually be seen escaping the local ventilation. Thus, we were not surprised to find that the furnace workers also had very high levels of blood lead; and that drinking, smoking, and wearing a cotton mask did not have a significant impact on blood lead. Because lead dust coming from workers' shoes could also be easily seen on the ground of the office, the average blood lead level of office workers was as high as  $37.8 \pm 4.2 \mu\text{g/dl}$ . This was almost 3 times higher than the average for traffic policemen in Taipei [11]. Only the sales people and the company manager, who worked outside of this factory, had normal blood lead levels. Thus, a prevalence rate of 86% of workers having blood lead levels exceeding  $40 \mu\text{g/dl}$  indicated that this was a very hazardous and dirty workplace which needed a significant improvement in occupational health, and that a worker might have a blood lead level over 80

$\mu\text{g}/\text{dl}$  after only 50 days of working in this site.

We found that symptoms of abdominal colic or diarrhea usually occurred if blood lead exceeded  $60 \mu\text{g}/\text{dl}$ . Our findings were similar to those described by other investigators [12 - 14]. However, here the prevalence of bowel symptoms was only about 25%, which was somewhat lower than others have found [14, 15]. We attribute this difference to our definition of positive symptoms as occurring at least twice a week. This definition may be more restrictive than that of other investigators.

Because workers with an overt weakness of extensor muscles in our study had a minimal working duration of 50 days, we suggest that a minimal induction time for overt lead polyneuropathy may be about 50 days. 12 out of 13 workers with anemia had already worked inside the smelter for more than 110 days, which is compatible with the theory that lead affects the hematologic system by suppressing the heme synthesis. We did not find any abnormal liver or kidney function although some studies have showed impairment of these organs [16 - 18]. Because most of our workers were exposed for less than 2 years (Table 1), our findings may indicate that it takes a longer exposure to cause such damage. After our study, we recommend a medical protection removal (MPR) to all workers diagnosed with lead poisoning. Although a lot of them did take our advice, some continued their work for fear of losing their bonus, which has accounted for a big proportion of their wages.

The Council of Labor Affairs estimates that 1,537 workers are directly exposed to lead in lead battery making or recycling and lead stearate manufacturing and usage in Taiwan [19]. Battery recycling involves less exposure than the other processes (medians were  $0.10 \text{ mg}/\text{M}^3$  vs.  $0.51$ ,  $0.13$ ,  $0.21 \text{ mg}/\text{M}^3$  for battery making, lead stearate manufacturing, and usage, respectively). Therefore, we fear that the prevalence rate of occupational lead poisoning in Taiwan is probably higher than was found in this study. Because there is a limited number of occupational physicians in Taiwan and lead-related factories are distributed rather extensively throughout the island, we believe that the development of a simple and convenient test will make it easier for local doctors or other primary health workers such as factory nurses to easily recognize occupational lead poisoning in all such factories. As blood lead level is the simplest test for early detection of increased lead absorption before overt poisoning occurs, we recommend its use for biological monitoring of lead workers. Primary care physicians should also be aware that if a worker who is occupationally exposed to lead shows either bilateral weakness, (or  $\text{B.S.RBC} \geq 8/1000$  if such a test is available), he is very likely to have lead poisoning as shown in Table 5. We hope that through regular measurement of blood lead levels, careful recognition of lead poisoning by primary health workers, and effective improvements in the occupational hygiene at lead factories, pollution at workplaces will be controlled quickly and cases



of occupational lead poisoning will become rarer and rarer in the near future in Taiwan.

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## 鉛蓄電池回收廠熔煉工人之鉛中毒

張常勝<sup>1</sup> 王榮德<sup>2</sup> 黃耀輝<sup>3</sup> 張揚全<sup>4</sup>

埔里基督教醫院<sup>1</sup>

台灣大學公共衛生學院職業醫學與工業衛生研究所<sup>2</sup>

環境衛生博士 美國辛辛那提大學環境衛生研究所<sup>3</sup>

台大醫院神經科<sup>4</sup>

### 摘 要

本研究之目的在了解臺灣北部某鉛蓄電池回收廠員工鉛中毒的盛行率、危險因子、和症狀。在110位員工之中，有64位（58.2%）接受我們的體檢。每一位員工都接受詳細的檢查，包括問卷、神經學檢查、血中鉛、全血球計數、嗜鹼性顆粒紅血球計數、血清肌氨酸酐、血液尿素氮、天門冬酸轉氨基酶（Aspartate aminotransferase）、丙胺酸轉氨基酶（Alanine aminotransferase）、和常規尿液檢查。血中鉛以原子吸收光譜測定法（Atomic absorption spectrophotometry）測量。結果顯示有55位員工的血中鉛超過 $40\mu\text{g}/\text{dl}$ ，並且31位員工被診斷為鉛中毒。在熔爐、維修、和工地清潔（只有男性）的工人，其血中鉛平均值超過 $80\mu\text{g}/\text{dl}$ 。在切割、精煉、或堆高機的工人其血中鉛平均值則在60到 $70\mu\text{g}/\text{dl}$ 之間。即使辦公室職員和警衛的血中鉛值也有 $38.5 \pm 4.9\mu\text{g}/\text{dl}$ 。抽煙、喝酒、和戴口罩與血中鉛值高低無統計相關。血中嗜鹼性顆粒紅血球隨著血中鉛之增加而增加。和其他症狀的組合比較，以嗜鹼性顆粒紅血球數 $\geq 8/1000$ 或神經學徵象陽性，兩者存在至少一項為依據，其診斷準確率為最高。我們的結論為：鉛中毒在臺灣是一種嚴重的職業病，需要儘速控制。

關鍵詞：鉛、熔煉廠、異常腹絞痛、貧血、嗜鹼性顆粒紅血球、多發性神經病變