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Original Article

An Examination of Blood Lead Levels in Thai Nielloware Workers

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Objectives: The objectives of this study were to determine the lead levels in blood samples from nielloware workers, to determine airborne lead levels, to describe the workers' hygiene behaviors, and to ascertain and describe any correlations between lead levels in blood samples and lead levels in airborne samples.
Methods: Blood samples and airborne samples from 45 nielloware workers were collected from nielloware workplaces in Nakhon Sri Thammarat Province, Thailand. Lead levels were determined by flame atomic absorption spectrometry (FAAS), at a wavelength of 283.3 nm. FAAS was used especially adequate for metals at relatively high concentration levels.
Results: The geometric mean of the 45 airborne lead levels was 81.14 μg/m^3 (range 9.0-677.2 μg/m^3). The geometric mean blood lead level of the 45 workers was 16.25 μg/dL (range 4.59-39.33 μg/dL). No worker had a blood lead level > 60 μg/dL. A statistically significantly positive correlation was found between airborne lead level and blood lead levels ($r = 0.747$, $p < 0.01$). It was observed that personal hygiene was poor; workers smoked and did not wash their hands before drinking or eating. It was concluded that these behaviors had a significant correlation with blood lead levels ($p < 0.001$).
Conclusion: Improvements in working conditions and occupational health education are required due to the correlation found between blood leads and airborne lead levels.

Key Words: Inorganic lead, Home workers, Small enterprises

Introduction

The term "nielloware worker" refers to workers in the nielloware industry who work at home and/or at small enterprises. They are informal workers. The process of making nielloware is traditional [1]. Niello-making is the art of fashioning receptacles by the application of lead amalgam, superimposed on, or poured into, incised designs. The term "factory" in this study refers to a small enterprise where workers may be exposed to inorganic lead through a variety of nielloware-making processes, including making the niello amalgam, shaping the object, drawing the patterns, engraving or chiseling, applying the niello, filing the surface of the object, reshaping, and polishing and burnishing the object [1].

Exposure to inorganic lead is a ubiquitous hazard of the nielloware process. The high-risk stages of the nielloware process, include exposure to metal fumes while making the niello, and metal dust when filing and polishing the object's surfaces.

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Inorganic lead poisoning is usually associated with clinical evidence of anemia, toxic encephalopathy, and peripheral neuropathy. Such subclinical evidence of lead poisoning has been reported in neurophysiological studies [2,3].

In developing countries, such as Thailand, many workers in small- and medium-sized industries face lead exposure hazards. Nielloware workers, who perform piecework at home, are at risk of exposure to inorganic lead. Much of the fine work involved in preparing and finishing jewelry is physically demanding. Jewelers confronted with urgent deadlines may work long hours and occasionally sleep at their workplaces. In addition, lack of suitable ventilation, inadequate knowledge of personal protective equipment, and inadequate awareness of health hazards in the workplace, increase the risk of exposure [4]. Lead contamination and poisoning have been reported among workers in other industries using lead [5,6]. However, lead-exposure data for nielloware workers remain limited. The objectives of this study were to the measure blood lead and airborne lead levels among nielloware workers, to investigate nielloware-making processes and workers' hygiene behaviors, and to determine any correlation between blood lead and airborne lead levels.

Materials and Methods

Study site and study subjects

Data for this cross-sectional study were collected by sampling from 45 nielloware workers (27 males; 18 females) in Nakhon Sri Thammarat Province, from August-September 2009. Twenty-five nielloware workers were recruited from 5 small factories, and an additional 20 nielloware workers were recruited from informal workers or home workers.

In this study, the process of nielloware production included making niello amalgam, shaping the object, drawing patterns, engraving or chiseling, applying niello, filing the surface of the object, and reshaping, polishing, and burnishing the object. Inclusion criteria for the study subjects were as follows: nielloware work, aged 20-60 years, in direct contact with heavy metals, and working in nielloware for at least one year prior to the study; persons who had been in occupational contact with lead fumes and dust during nielloware production; persons who agreed to participate in the study and who signed the informed consent form. The study protocol was approved by the Ethics Committee of the Faculty of Tropical Medicine, Mahidol University. Detailed data on the nielloware process and working conditions were collected by a walkthrough survey, an interview, and by observation. For sample collection, the 45 subjects were interviewed using a questionnaire. The questionnaire consisted of general characteristics, work environment, and personal hygiene practices. The patterns of behavior reported in the questionnaire were confirmed by direct observation. Whole blood was collected from the study participants at the end of their work shift.

Airborne lead specimens were collected during August 2009. Regarding the instruments for air sampling, personal sampling pumps (Model 224-PCXR8; SKC Inc., Eighty Four, PA, USA) were calibrated at a flow rate of approximately 2.0 L/min, containing a mixed cellulose ester membrane filter (pore size 0.8 μm), and were connected at the collar of the nielloware workers. The procedure was specified by the National Institute for Occupational Safety and Health (NIOSH) method 7082/1994 [7]. A medical technologist collected 5 mL of venous blood by venipuncture from each subject; the samples were kept in polypropylene tubes with lithium heparin as an anticoagulant. The blood-sample collection method followed NIOSH 8003/1994 [8]. About 5 mL were transferred to heparinized lead free plastic tubes. The blood specimens were mixed immediately and placed in a container with ice packs to maintain a temperature of approximately 4°C, monitored by thermometer, for transfer to the laboratory for analysis.

Sample preparation

Airborne sample preparation

The cassettes filters were held and the samples were transfered to clean beakers and 1 mL + 3 mL (30% H_2O_2 + concentration of HNO_3) were added. The samples should be heated at 140°C on a hotplate until the volume is reduced to about 0.5 mL. These steps were repeated 2 times. Each beaker was cooled and the residues were dissolved in 1 mL concentration of HNO_3. Transferred to the solution quantitatively to a 10 mL volumetric flask and dilute to a volume with distilled water.

Blood lead sample preparation

Blood lead sample preparation place 2 mL of whole blood into a culture tube. Start a reagent blank at this point with 2 mL deionized water and 0.8 mL of diluted solution (ammonium pyrrolidine dithiocarbamate) was added. The samples were mixed on a rotary vibration mixer for 10 seconds. Then, 2 mL of water saturated with methyl isobutyl ketone (MIBK) were added to the mixture. Each culture tube was capped and rotated on a rotary vibration mixer for 2 minutes. Next, the samples were centrifuged at 2,000 rpm for 10 minutes. Next, the samples were analyzed with Lead Ammonium pyrrolidine dithiocarbamate (Pb-APDC) solution in MIBK within 2 hours of extraction.

Sample analysis

Airborne lead and blood lead analysis

Airborne lead levels were measured by Hitachi Model Z-8200 (Hitachi Ltd, Tokyo, Japan) flame atomic absorption spectrophotometer, according to NIOSH method 7082/1994 [7].

Lead levels in whole blood were measured using the same apparatus, according to NIOSH method 8003/1994 [8]. All samples were measured at a wavelength of 283.3 nm, with a slit width of 1.30 nm. Electricity was supplied to the lead hollow-cathode lamp at 12 nm. The temperature stages comprised drying at 50-140°C, ashing at 400-500°C, atomizing at 2,000°C, cleaning at 2,400°C, and cooling at room temperature.

Calibration, recovery and reproducibility

Whole blood lead determination was calibrated by preparing a series of standard additions, i.e., 0, 5, 10, 20, 30, and 50 μg/dL. The correlation coefficient (r) between the lead concentration in the authentic lead solution and the absorption intensity was 0.9998. The limit of detection was defined as the concentration of the element equal to the signal blank, plus 3 times the standard deviation (SD) of the blank ($3SD_b/S$). The limit of quantitation was defined as the lower limit for precise quantitative measurement, given as the value of the signal blank plus 10 times the SD of the blank ($3SD_b/S$) at 4 μg/dL. The calculation method is again based on the standard deviation of the response (SD) and the slope of the calibration curve (S) according to the formula: LOQ = 10 (SD/S). The accuracy of the whole blood lead test results was ascertained by comparisons with known samples of Seronorm™ Trace Elements (SGAB AS-Whole Blood L-2, Sero, Germany). A known sample containing added Seronorm™ Trace Elements, 0.5, 1.0, and 2.0 μg/dL, was used in determining within-day accuracy and between-day precision of the method. The RSDs (100 × SD/mean) were calculated for 10 days for between-day precision. The accuracy of the overall method ranged between 82.6-92.5%, and the calculated precision was within 12% RSD.

Table 1. Airborne lead and blood lead levels of nielloware workers

Parameter	Geometric mean	Range
Airborne lead levels (μg/m^3, n = 45)	81.14	9.0-677.2
Blood lead levels (μg/dL, n = 45)	16.25	4.6-39.3

n = air samples and blood lead samples collected from 45 nielloware workers.

Table 2. Number of workers and geometric mean of airborne lead levels in breathing zone, classified by nielloware processes

Nielloware process	n (%), Geometric mean (range)		
	n	≤ 200 (μg/m^3)	> 200 (μg/m^3)
Making the niello	13	3 (23.1) 23.7 (15.36-36.0)	10 (76.9) 342.7 (255.9-522.4)
Shaping the object	37	22 (59.5) 26.4 (9.0-44.2)	15 (40.5) 352.8 (205.2-677.2)
Drawing patterns	41	23 (56.1) 25.7 (9.0-44.2)	18 (43.9) 331.5 (255.9-677.2)
Chiseling	33	17 (51.5) 24.9 (9.0-44.2)	15 (45.5) 356.8 (205.2-677.2)
Applying the niello amalgam	17	8 (47.1) 27.9 (9.0-155.9)	9 (52.9) 369.4 (205.2-522.4)
Filing the object's surface	37	24 (64.9) 28.1 (9.0-155.9)	13 (35.1) 350.3 (209.9-677.2)
Reshaping and polishing the object	11	4 (36.4) 28.9 (4.0-42.2)	7 (63.6) 340.8 (201.2-501.0)
Engraving	10	6 (60.0) 33.7 (15.6-155.9)	4 (40.0) 338.3 (298.2-406.6)
Burnishing	6	4 (66.7) 32.3 (15.6-155.9)	2 (33.3) 323.5 (298.2-350.9)

n = number of nielloware workers who performed each nielloware process.

Statistical analysis

Descriptive statistics were used to present the airborne and whole blood lead concentration results. The independent t-test was used to compare the means of continuous variables. Pearson's test was used to test the association of airborne and blood lead levels. Normally distributed data were compared using the Student's t-test. Statistical significance was defined as $p < 0.05$.

Table 3. Comparison of blood lead levels in nielloware workers, classified by nielloware processes

Nielloware process	Performed nielloware process	n	n (%), Geometric mean (range)		p-value
			< 30 (μg/dL)	≥ 30 (μg/dL)	
Making the niello	Yes	13	5 (38.5) 25.1 (21.7-29.4)	8 (61.5) 35.1 (31.6-39.3)	< 0.001*
	No	32	31 (96.9) 13.7 (4.6-24.4)	1 (3.1) 34	
Shaping the object	Yes	37	32 (86.5) 13.9 (4.6-29.4)	5 (13.5) 33.8 (31.6-38.3)	0.051
	No	8	4 (50.0) 24.2 (21.7-27)	4 (50.0) 36.5 (33.6-39.3)	
Drawing patterns	Yes	41	35 (67.4) 13.5 (4.6-28.4)	6 (14.6) 34.0 (31.6-38.3)	0.003*
	No	4	1 (25.0) 27	3 (75.0) 37.0 (33.6-39.3)	
Chiseling	Yes	33	28 (84.9) 14.1 (4.5-29.4)	5 (15.1) 33.8 (31.6-38.3)	0.243
	No	12	8 (66.7) 12.7 (5.0-25.3)	4 (33.3) 36.5 (33.6-39.3)	
Applying the niello amalgam	Yes	17	9 (53.0) 21.1 (18.3-29.4)	8 (47.0) 35.1 (31.6-39.3)	< 0.001*
	No	28	27 (96.4) 13.3 (4.6-22.0)	1 (3.6) 34	
Filing the object's surface	Yes	37	25 (67.6) 13.9 (4.6-29.4)	12 (32.4) 31.9 (31.6-32.3)	< 0.001*
	No	8	1 (12.5) 23.1	7 (87.5) 35.9 (33.1-39.3)	
Reshaping and polishing the object	Yes	11	4 (36.4) 20.8 (18.6-23.2)	7 (63.6) 35.9 (33.1-39.3)	< 0.001*
	No	34	32 (94.1) 13.9 (4.6-29.4)	2 (5.9) 31.9 (31.6-32.3)	
Engraving	Yes	10	5 (50.0) 21.9 (19.9-24.2)	5 (50.0) 36.9 (33.6-39.3)	0.070
	No	35	31 (88.5) 13.7 (4.6-29.4)	4 (11.5) 32.7 (31.6-34.0)	
Burnishing	Yes	6	4 (66.7) 24.2 (21.7-27)	2 (33.3) 35.8 (33.6-38.3)	< 0.001*
	No	39	32 (82.1) 13.9 (4.6-29.4)	7 (17.9) 34.7 (31.6-39.3)	

*Statistical significance at $p < 0.05$.
Yes: number of nielloware workers who performed this process, No: number of nielloware workers who did not perform this process.

Results

Demographic characteristics of the subjects

The nielloware workers' ages ranged between 20-55 years (mean 35.33 years). The largest group of workers (35.6%) was aged 20-30 years. All workers were Buddhist. The largest group had primary-school level educations (29.0%) and was married (57.8%). The geometric mean airborne lead level was 81.14 $\mu g/m^3$ (range 9.0-677.2 $\mu g/m^3$), which was below the standard of the Ministry of Labor and Social Welfare, Thailand, of 200 $\mu g/m^3$ (Table 1). Nineteen (42.2%) of the airborne nielloware-processing lead-levels were highest, and exceeded the standard of the Ministry of Labor and Social Welfare, Thailand (200 $\mu g/m^3$) [9]. The Thai standard level is higher than the 50 $\mu g/m^3$ time-weighted average for airborne lead [10], and 50 $\mu g/m^3$ Occupational Safety and Health Administration (OSHA) [11]. The overall range for blood lead levels was wide, with a geometric mean of 16.25 μg/dL (range 4.6-39.3). OSHA has defined the threshold for concern about workers' blood lead levels as 40 μg/dL [10], whereas the Ministry of Public Health, Thailand, has defined it as 60 μg/dL [12]. However, no nielloware worker in this study had blood lead level ≥ 60 μg/dL. The blood lead levels of the nielloware workers are shown in Table 1. The geometric mean airborne lead levels, classified by stage of the nielloware fabrication process, are shown in Table 2. The workers were at high-risk of direct contact with lead, and high geometric means were found for airborne lead in the production of niello, applying the niello amalgam, filing the object's surface, and reshaping and polishing the object. Workers involved in the processes of shaping the object, drawing patterns, chiseling, engraving, and burnishing, were at lower risk of contact with lead and had a lower geometric mean of airborne lead level.

Blood lead levels of the nielloware workers

Geometric mean blood lead levels classified by nielloware fabrication process, are shown in Table 3. The nielloware workers at high risk of lead exposure, and high geometric mean of blood lead levels, worked in the production phases of making the niello, drawing patterns, applying the niello amalgam, and filing the object's surface. The nielloware workers involved in the processes of reshaping and polishing the object and burnishing were at lower risk of contact with lead and had lower geometric mean of blood lead levels. The blood lead levels of workers in the processes of shaping the object were not significantly different from those in chiseling and engraving ($p < 0.05$).

In this study, we compared average blood lead levels between different working conditions and the personal hygiene

Table 4. Comparison between blood lead level and workplace environmental conditions and personal hygiene of nielloware workers (n = 45)

Parameters		n	Mean blood-lead level (SD, μg/dL)	p-value*
Working environment				
Type of workplace	House	20	24.39 (5.32)	< 0.001
	Factory	25	14.62 (3.42)	
Working and living in the same area	Yes	20	25.35 (3.40)	< 0.001
	No	25	14.25 (3.20)	
Ventilation system used	Natural ventilation	19	25.48 (5.04)	< 0.001
	Electric fan	26	14.58 (3.95)	
Personal hygiene				
Smoking	No	3	6.03 (1.25)	< 0.001
	Yes	42	20.13 (5.02)	
Wash hands (before eating)	Sometimes	32	23.89 (4.22)	< 0.001
	Always	13	7.61 (0.10)	
Eating snack (during work hours)	Sometimes	6	5.63 (1.01)	< 0.001
	Always	39	21.09 (3.12)	

*Statistical significance at $p < 0.05$.
SD: standard deviation.

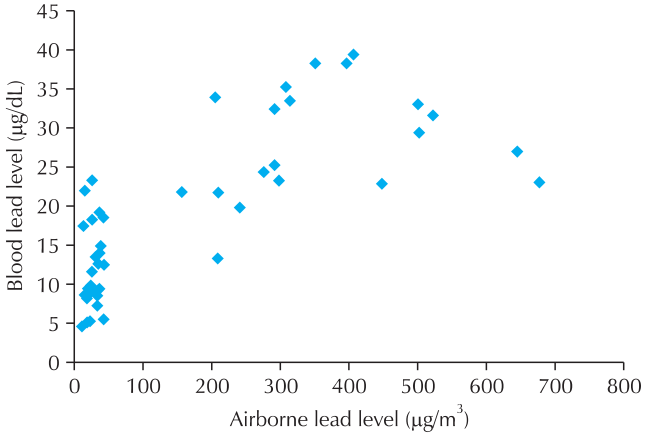

Fig. 1. The correlation plot of airborne lead levels (personal sampling) versus nielloware workers' blood lead levels.

practices of nielloware workers (n = 45). The blood lead levels of the nielloware workers are shown in Table 4. The average blood lead levels of the workers in houses were significantly higher than those in factories. For those who worked in their houses, individual who worked and lived in the same place had significantly higher blood lead levels than those who did not. The different type of ventilation systems used were leaded to significantly different blood lead levels ($p < 0.001$). The average blood lead levels of workers who used electric fans were significantly lower than for those who did not. The geometric mean of blood lead level among smoker and non-smokers were 20.13 ± 5.02 μg/dL (5.12-39.33 μg/dL), and 6.03 ± 1.25 μg/dL (4.57-8.52 μg/dL), respectively.

The blood lead level of workers who always washed their hands before eating had significantly lower blood lead levels than those who sometime did ($p < 0.001$). The workers who always ate snack at work had significantly higher blood lead levels then those who sometime did ($p < 0.001$).

Correlation between blood-lead and air-borne lead levels

Fig. 1 shows the correlation between the airborne lead levels (personal sampling) and the blood lead levels of the nielloware workers. The relationship between airborne and blood lead levels was significant ($r = 0.747$, $p < 0.01$).

Discussion

Blood lead level is commonly used as an indicator of lead exposure among humans [13]. This study ascertained the airborne and blood lead levels among a selected group of nielloware workers. The blood lead levels of all nielloware workers were < 40 μg/dL [11], the minimum level for concern by OSHA, and the 60 μg/dL recommended by the Ministry of Public Health, Thailand [12].

The geometric mean of airborne lead level was 81.14 μg/m^3 (range 9.0-677.2 μg/m^3), which did not exceed the 200 μg/m^3 defined by the Ministry of Labor, Thailand. However, 42.2% of airborne lead samples exceeded the standard of the Ministry of Labor and Social Welfare, Thailand (200 μg/m^3) [10]. The results showed that the highest-risk production phases were making the niello, drawing patterns, applying the niello amalgam, and filing the object surface, when workers were directly exposed to lead fumes or lead dust. The results of the present study were similar to the study of Chuang et al. [14], where different jobs in a battery factory had different levels of occupational exposure. Working in the highest-risk jobs, such as, pasting and plate cutting, was associated with blood lead levels > 20 μg/dL. This study found that most nielloware workers did not use personal protective equipment. Self-protection is important, because the risk of exposure to hazardous materials can be reduced by implementation of appropriate behaviors. This result was supported by Rogers [15]. The present study also agreed with Lai et al. [16], who reported that exposure to lead fumes contributed to elevated blood lead levels. Therefore, education in appropriate hygiene practices could help nielloware workers to protect themselves in the current working conditions. The training on correct personal hygiene practices is an easy and cost-effective way of preventing overexposure to lead. With regards to environmental working conditions, it was found that average blood lead levels differed depending on types of workplaces. Nielloware workers who used their houses as their workplaces had significantly higher blood lead levels than those who did not. In addition, differences in types of ventilation systems were related to significant differences of blood lead levels. This result is also supported by the study of Chuang et al. [14], who suggested that improved work areas and engineering control systems (such as general and local ventilation) would be the best ways to lower blood lead concentrations of battery workers'. The present study agreed with Lai et al. [16], who reported the relationship between ambient lead and blood lead among lead-battery workers. Because of improved ventilation technology, a 30-year-old man could have a blood-lead level of 43.6 μg/dL, when exposed to 0.1 mg/m^3 ambient lead. If the air-borne lead concentrations were lowered to 0.05 mg/m^3, the blood lead level of the 30-year-old male worker would only be reduced to 39.6 μg/dL. This was also supported by Luang-on et al. [17], who reported on occupational lead poisoning in Thailand (1992-2001). It was found that boatyards were one of the top-3 risky workplaces, where workers showed the highest mean blood lead levels. Thus, environmental working conditions needed to be improved.

This study found a correlation between airborne and blood lead levels ($r = 0.747$, $p < 0.01$). This result agreed with Karita et al. [18], who reported a correlation between blood lead and airborne lead levels among copper-smelter workers in Japan. The relationship between ambient lead level and blood lead level among lead-exposed workers has been the subject of a number of studies [19-21]. The main pathway for raising blood lead levels among nielloware workers is probably inhalation route. This is supported by Chuang et al. [14]. However, lead contamination of hands, clothes, and work surfaces can occur. Poor hygiene behaviors may therefore be associated with elevated blood lead levels. Lead contamination could occur by direct hand-to-mouth contact, and indirectly through contamination of hands, food, drinking water, cigarettes, etc. This is also supported by Askin and Volkmann [22], who reported the effects of personal hygiene on the blood lead levels of workers at a lead-processing facility. Thus, elevated blood lead levels might result from inappropriate behaviors, such as hand-mouth contact with infrequent hand-washing before eating and drinking. The geometric mean of blood lead level in this study was 16.25 μg/dL, which did not exceed the cited respective Thai and international entire standards. However, the effects of low-level lead exposure on renal function among Canadian copper-smelter workers have been reported as a matter for concern, and was supported by Lilis et al. [23]. Disorders of neurological and systemic function can occur, as reported by several studies [24-26]. In addition, compared with the normal population, higher rates of malignant neoplasms, especially lung and stomach cancers, ischemic heart disease, and cerebrovascular diseases, were found among Swedish smelter workers with elevated lead levels (Gerhardsson et al.) [27]. The World Health Organization/International Programme on Chemical Safety reported that clinical lesions may result from blood lead levels ≥ 20 μg/dL [28]. Occupational health education is fundamental tools in the prevention of occupational diseases [29]. In addition, respiratory equipment should be used to supplement the engineering measures and the work control. Demonstration of wearing an appropriate mask was given. This results showed that the occupational health management in Korean. The successful achievement of prevention of lead poisoning in Korea was a result of the combined efforts of lead workers, employers, relevant government agencies, and academic institutes [30]. In conclusion, this study demonstrated blood lead levels were associated with airborne lead levels and hygiene behaviors of Thai nielloware workers. The hygiene behaviors of nielloware workers and the environments of nielloware manufacturing workplaces should be monitored annually. The bio-monitoring of heavy metals and airborne lead levels of Thai nielloware workers should be done regularly to evaluate the effectiveness of any interventions implemented. The health of nielloware workers should be monitored with a systematic surveillance system.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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