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Exposure to Lead of Boatyard Workers in Southern Thailand

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Abstract: Exposure to Lead of Boatyard Workers in Southern Thailand: Chamnong THANAPOP, *et al*. Epidemiology Unit, Faculty of Medicine, Prince of Songkla University, Thailand—Lead oxide is used extensively in the construction and repair of wooden boats in Thailand, but the behaviors of boatyard workers that could place them at risk of contamination have not previously been documented. Baseline data on practices and behaviors of boatyard workers and on the level of worker and workplace contamination with lead were therefore collected. Fifty workers in two boatyards participated in this study. Lead exposure of workers was assessed by determining airborne and blood lead levels. A questionnaire was administered to collect information on work history, suspected exogenous lead sources, personal behavior and knowledge about lead. Evidence obtained by the study indicated that safety behavior and personal hygiene were poor—workers used no mask, gloves or hood, wore open sandals, smoked, drank, chewed and ate during work and did not wash their hands before drinking or eating. Some workers had lunch in the working area. The mean personal airborne lead of caulkers (36.4 μg/m^3) was higher than that of carpenters (8.3 μg/m^3). Forty-eight percent of all workers and 67% of caulkers had a blood lead level (BLL) exceeding 40 μg/d*l*. Multiple linear regression indicated that blood lead levels of workers were significantly related to job and education level, with significant differences between boatyards. In addition, the potential for "take-home" contamination was high; none of the workers took a shower or changed their clothes prior to going home. These results indicate a problem of lead exposure of sufficient magnitude to be a public health concern.
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Despite the decline in blood lead levels among the general population during the past 20 yr, lead continues to be a public health concern for individuals with past and present lead exposure. Lead poisoning due to long-term exposure at work is one of the major occupational diseases worldwide[1)].

In developing countries like Thailand, many workers in small and medium size industries are faced with problems of lead exposure. Boat repair is one such industry that is widespread in coastal areas of the country. Records from the Department of Industrial Works, Ministry of Industry, show that there were 220 boatyards in 2004[2)].

In boatyards, lead oxide (Pb_3O_4) is used in the process of caulking wooden boats and boat-repair workers are readily exposed to this compound. The Division of Epidemiology, Ministry of Public Health, also reported a situation analysis of occupational lead poisoning in Thailand from 1992 to 2001, which demonstrated that the trend of lead poisoning among Thai workers was increasing progressively[3)]. The boatyard was reported as one of the top three risky workplaces where workers showed the highest mean blood lead levels[4)].

Lead contamination and poisoning of workers in other industries using lead have been reported[5, 6)]. Lead contamination of children and households in communities close to boat-repair yards has been documented[7)]. However, lead contamination among boat-repair workers in Thailand has not been addressed in detail despite the obvious hazard and size of the problem.

The objectives of this study, therefore, were to document the boat-repair process, determine and evaluate the level of airborne lead concentration in the boatyard and blood lead levels of boat-repair workers. Additional objectives were to describe worker behaviors, and

evaluate them in terms of their possible role in worker contamination and transfer of lead to the home.

Materials and Methods

Study population and sample size

1) Boatyard

The study was set in two boat-repairing and building yards in one area of Nakhon Si Thammarat province, southern Thailand, which had regular work activity throughout the year and in which workers either had fixed work in one boatyard or moved from yard to yard within the district.

General information on the boatyards was collected by face-to-face interview of boatyard owners using a survey form and by walk-through survey, on-site. The survey form was designed to answer the following issues to evaluate the present status of boatyards: history of operation, productivity, number of workers, working hours, facilities in the workplace such as canteen, dressing rooms, bathrooms, lavatories and personal protective equipment supply, and general cleanliness. The boat-repair process and working conditions were examined by walk-through survey, interview and observation.

2) Subjects

All workers working in the two boatyards at the time of the study were asked to participate and all consented. There was a total of 50 workers, 27 and 23 workers in boatyards no.1 and no.2, respectively, comprising 36 caulkers, 9 carpenters and 5 technicians.

Specimen collection

1) Airborne lead

Airborne lead specimens were collected from April 7 to 24, 2005, using area and personal sampling. Representative area air specimens from 3 sites spaced throughout the working area were collected to characterize the general environmental concentration of airborne lead over the time of the workday (7.00–17.00 h). Specimens of airborne lead were gathered using a 37-mm diameter 0.8-μm pore mixed cellulose ester membrane filter and a three-piece filter holder cassette and personal sampling pumps (model 224-PCXR8; SKC Inc.; Eighty Four, Pa) calibrated at a flow rate of approximately 2.0 *l*/min (Drycal; model DCLT 20k Rev.1.08, BIOS International Corp.) at a height of 1.5 m, corresponding approximately to face height of a standing worker. The procedure is specified in the NIOSH method 7082/1994[8]. Area lead specimens were collected on two work days.

Two personal airborne lead specimens were collected in the personal breathing zone of each of 25 workers (22 caulkers and 3 carpenters) on each of two consecutive working days. Specimens were collected over four and a half hour periods, from 07.00 to11.30 h and from 12.30 to 17.00 h, excluding the lunch period. For each day, morning and afternoon specimens were averaged and the time weighted average calculated. Two field blanks per set were used for quality control purposes.

2)Blood Lead Specimens

Blood specimens were collected on 4th May, 2005, at the boatyards. After written consent had been obtained from the workers, venous blood specimens were collected by a registered nurse at an office room. A blood specimen of volume 4 ml was drawn from the cubital vein of each worker. Specimen collection method followed the NIOSH method 8003/1994[9] using a 10-m*l* sterile plastic syringe containing heparin as an anticoagulant. About 3 m*l* 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 analysis

Airborne lead and blood specimens were analyzed by the Central Equipment Unit, Faculty of Tropical Medicine, Mahidol University. Airborne lead specimens were analyzed by flame atomic absorption spectrophotometer (AAS) according to NIOSH method 7082/1994[8]. If a specimen result was below the analytical limit of detection (LOD) for method 7082 (LOD=0.01 ppm), the specimen was subsequently analyzed by graphite furnace AAS using NIOSH method 7105/1994[10], which has a lower LOD (0.0002 ppm). Blood lead was analyzed by graphite furnace AAS (Hitachi Model Z-8200) with a LOD of 0.5 μg/d*l*.

Behavior and knowledge of workers

Workers were face-to-face interviewed by a researcher using a questionnaire regarding their current and past activities. The questionnaire was administered to collect information on work history, suspected exogenous lead sources, and personal behavior and activities such as working hours, eating at the work site, hand washing, smoking habits at work, alcohol use, and medication. Also, the frequency of use of personal protective equipment (PPE) (such as gloves, mask) was recorded on this questionnaire. Direct observation was also used to confirm the patterns of behavior reported in the questionnaire.

In addition, a lead knowledge questionnaire was administered to record the knowledge of the workers, consisting of 20 True/False questions on sources of lead inside and outside the boatyard, lead contamination route, simple toxicity, and lead contamination prevention. Correct answers were summed to provide a score of knowledge about lead with the possible range of 0 to 20. Pilot testing of the questionnaire was done among non-

study boat-repair workers at boatyards in a different area.

Statistical analysis

Statistical analysis was performed using Stata version 7.0. A logarithmic transformation was used where necessary to correct skewness in the distribution. Normally distributed data group means were compared using Student's t-test or ANOVA for 2 or more than 2 groups, respectively. Relationships between blood lead levels and influencing factors were estimated using multiple linear regression, in which the significance of each variable was assessed using partial F- tests. Fitting BLL in its original metric resulted in model residuals that exhibited significant heteroskedasticity, and the model was refitted using the logarithmic transform of BLL.

Ethical consideration

The study proposal was approved by the Ethics Committee, Faculty of Medicine, Prince of Songkla University. Workers were asked to participate in the study. The researcher explained the purposes, the research procedure and benefits of the study and each worker was asked to give written consent.

Results

General characteristics of the boatyards

In general, both boatyards in the study had a similar production process, number of workers, style of employment, working hours, facilities and operation period. The average productivity in boatyards numbers 1 and 2 was 7 and 10 boats per month, respectively. The workforce in each boatyard comprised caulkers, carpenters, technicians, painters and a clerk. Most workers other than the technicians and clerks were in the informal sector and received a daily wage. Most of the caulkers had fixed work in one boatyard but carpenters and painters tended to move from yard to yard within the district. They were not provided with facilities such as hand-washing or shower facilities, personal protective equipment (PPE), annual health examination or environmental monitoring by the employers. They had a nine-hour working day plus one hour for rest.

Boat-repairing process

The boat-repair process involved four main activities:

1) Boat transfer from pier to yard on a conveyer attended by technicians and/or caulkers.
2) Wood and machine inspection and repair; checking for decayed timber, scrubbing old paint with an electrical grinder, and replacing decayed wood with new wood.
3) Caulking: mingling lead oxide powder and yang oil with cotton yarn, pulling out decayed cotton that was plugged in between the wooden planks of the hull, re-caulking lead-mingled cotton yarn in the grooves between the wooden planks, and filling the groove again with a mixture of lead oxide, powdered gum dammar, yang oil and lime (Figs.1 and 2).
4) Painting the boat with oil-based paint.

Demographic characteristics of subjects

All but one of the workers were male - only one was a female worker (a caulker). The workers' age ranged from 21 to 82 yr with a mean of 48 yr. Most workers (42%) were in the age group of >50 to 60 yr. All workers were Buddhist. Most had only junior primary school education (66%) and were married (78%) (Table 1).

Airborne lead monitoring

The mean value of airborne lead in boatyard no.1 was 5.73 $\mu g/m^3$ (range 1.44, 8.17) whereas that in no.2 was 1.54 $\mu g/m^3$ (range 0.28, 4.75). There were six and three boats being repaired in boatyards number 1 and number 2, respectively, during the airborne lead collections.

Fig. 1. Mingling lead oxide and yang oil with cotton yarn.

Fig. 2. Pulling out decayed caulking material and re-caulking with lead-mingled yarn.

Table 1. Demographic characteristics of boat-repair workers (n=50)

Item	No.
Age (yr)	
20–30	7
>30–40	7
>40–50	10
>50–60	21
>60	5
Education	
Junior primary school	33
Senior primary school	10
Junior high school	4
Senior high school / Vocational school	3
Marital status	
Single	8
Married	39
Divorced	3

Personal airborne lead (time-weighted-average) was determined for each of 2 d for 22 caulkers (44 specimens) and 3 carpenters (6 specimens). The overall range of airborne lead in specimens from caulkers was wide (1.5 to 421.4 $\mu g/m^3$), whereas that in specimens from carpenters was narrow (2.9 to 23.1 $\mu g/m^3$). The mean personal airborne lead of caulkers (36.4 $\mu g/m^3$) was higher than that of carpenters (8.3 $\mu g/m^3$).

The Occupational Safety and Health Administration, USA, (OSHA) has defined the permissible exposure limit (PEL)[11] and the American Conference of Governmental Industrial Hygienists, USA, (ACGIH)[12] has defined the threshold limit value (time-weighted-average) for workers as an 8 h exposure to lead of 50 $\mu g/m^3$, whereas the Ministry of Labour, Thailand, has defined the permissible exposure limit as 200 $\mu g/m^3$. In caulkers, 9/44 specimens of personal air had lead equal to or exceeding 50 $\mu g/m^3$ and 1/44 air specimens had lead equal to or greater than 200 $\mu g/m^3$.

Blood lead levels (BLLs)

The overall range of BLLs was wide, 9 to 89 $\mu g/dl$. OSHA has defined the minimum level of concern for workers' blood lead as 40 $\mu g/dl$, whereas the Ministry of

Table 2. Variables* related to boat-repair workers' blood lead levels

Characteristic		No.	Mean ± SD of BLL ($\mu g/dl$)	*p*-value
Job	Caulkers	36	45.20± 13.39	<0.0001
	Carpenters	9	20.92 ± 7.50	
	Technician	5	15.77 ± 7.01	
Boatyard	Boatyard 1	27	31.64 ± 13.52	0.0034
	Boatyard 2	23	45.21 ± 17.63	
Age (yr)	≤40	14	28.28 ± 13.94	0.0167
	>40–55	23	39.03 ± 15.91	
	>55–82	13	46.19 ± 17.24	
Duration of work (yr)	≤ 20	31	33.83 ± 17.92	0.0281
	>20	19	44.50 ± 12.70	
Education	Junior primary	33	42.42 ± 16.90	0.0066
	Senior pri-Dip	17	29.09 ± 13.10	
Footwear	Shoes	18	37.08 ± 12.93	0.0442
	Sandals	25	42.20 ± 17.57	
	Both	7	24.53 ± 17.79	
Hand-wash before lunch	Sometimes	23	42.33 ± 12.48	0.0846
	Everytime	27	34.10 ± 19.22	
Mask	Not used	39	40.01 ± 16.04	0.0922
	Used	11	30.33 ± 18.16	
Trousers	Shorts	3	41.76 ± 13.84	0.1037
	Trousers	37	34.98 ± 18.09	
	Both	10	47.47 ± 7.01	
Knowledge score about lead	≤9 (<50%)	15	36.91 ± 13.91	0.1154
	10–13 (50–69%)	17	32.28 ± 15.55	
	14–20 (≥70%)	18	43.99 ± 18.92	

*Only those variable with *p*-value from *t*-test or ANOVA less than 0.2

Table 3. Final multivariate model of boat-repair workers' blood lead, fitted as loge (BLL in μg/d*l*)

Variable	No.	Coefficient	Multiplication factor (MF)	95% CI of MF	*p-value
Job					
Caulker	36	0	1		0.0000
Carpenter & technician	14	–0.8261	0.438	0.369–0.519	
Boatyard					0.0006
Boatyard 1	27	0	1		
Boatyard 2	23	0.2798	1.323	1.135–1.542	
Education					0.0007
Junior primary school	33	0	1		
Senior primary, diploma	17	–0.2905	0.748	0.637–0.879	
Constant		3.7196			0.0000

* p-value from partial F-test, R-squared=0.7579, adjusted R-squared =0.7421
Baseline blood lead level 41.25 μg/d*l*; 95% CI 36.25–46.94 μg/d*l*

Public Health, Thailand, defines it as 60 μg/d*l*. Forty-eight percent of all workers and 67% of caulkers had BLL exceeding 40 μg/d*l*. Only 14% of caulkers had BLL greater than 60 μg/d*l*.

Safety behaviors and knowledge about lead of workers

Workers in the boatyard did not use uniform work-garments. Most workers wore a short- or long-sleeved shirt and trousers. Over 50% of workers wore open sandals, and did not use any mask, gloves or cotton hood, but most workers wore a hat or cap. Regarding the safety behavior of workers, we found that during work most of the workers smoked (78%), drank water (100%), ate snacks (68%) and chewed kratom (78%) (*Mitragyna speciosa*, a tree native to Southeast Asia, whose leaves are chewed and act as a stimulant at low dose or a sedative at high dose[13]). Most of the workers did not wash their hands before drinking, eating snacks or chewing kratom but over 50% reported washing their hands every day before eating lunch. Most of the workers had lunch at a food shop or at home; five workers had lunch in the work area.

The results indicated that the mean BLL among different job types, boatyards, age groups, duration of work and education level were significantly different. Among the other variables obtained by the questionnaire, including wearing personal protective equipment (such as mask, glove, cap, and cotton hood), behavior during working hours and score of knowledge about lead, only type of usual footwear showed a marginally significant univariate relationship with BLL (Table 2), but this was strongly confounded by job type.

For behaviors related to take-home lead, we found that: some of the workers (16%) took hand tools back home; 66% of workers washed only their hands and face before going home but did not clean their shoes; 98% of workers never changed their clothes before going home; and 60% of workers did not shower until at least half an hour after returning home.

Modeling of workers' blood lead levels

Identification of factors associated with BLL was carried out using multiple linear regression. Variables initially included comprised job, boatyard, education level, duration of work, age group, hand washing before lunch, using mask, footwear and trousers, and knowledge score about lead (Table 2). Backward elimination of variables not significantly contributing to the fit of the model yielded a final model showing that job, boatyard and education level were independently and significantly associated with BLL (Table 3). BLL was higher in caulkers than in carpenters and technicians, in workers with lower education, and among workers in boatyard number 2 than in boatyard number 1. These variables together could explain about 74% of the variation in BLL. The residuals of the final model showed no evidence of heteroskedasticity using the Cook-Weisberge test (p=0.247).

Discussion

Overall, in our study sample almost half of the workers had a blood lead level exceeding 40 μg/d*l*, which has been set as the minimum level of concern by OSHA, USA, above which a worker must be provided with medical examination. According to the USA regulation, if a worker's blood lead level reaches 60 μg/d*l* (or average 50 μg/d*l* or more), the employer is obligated to remove the employee from excessive exposure, with maintenance of seniority and pay, until the employee's blood lead level falls below 40 μg/d*l*. No such action is taken for these

workers. These results indicate a problem of lead exposure of sufficient magnitude to be a public health concern.

Airborne lead monitoring

Airborne lead in the general environment of the boatyard was assessed by area sampling over two days in each boatyard. The much higher mean value of airborne lead in boatyard no. 1 than in no. 2, despite the normally higher productivity of boatyard 2, might have been a result of the higher number of boats being repaired and the larger quantity of lead oxide being used in boatyard no.1 at the particular time the measurements were made. There were 6 boats being repaired in boatyard no.1, compared with only 3 in boatyard no. 2. Thus environmental lead concentration in the boatyard may vary according to number of boats being repaired and the resulting quantities of lead oxide being used.

Estimates of occupational exposure at the personal level are usually more feasibly made and more valid than those obtained for exposure from ambient, dietary and other sources of the same agent. Personal airborne lead (time-weighted average) in caulkers was higher than in carpenters. Although both groups worked in the same area, the exposure to lead oxide among caulkers is more intimate.

Unusual work schedules that differ from the conventional 8-h day, 40-h work week require particular judgement in the provision of protection for such workers equal to that provided to workers on conventional work shifts. A model that addresses unusual work schedules is the Brief and Scala model (1975)[14]. In the boatyards of this study, the working day was 9 h so the TLV-TWA for workers' exposure to lead in the boatyards was equal to 41.7 μg/m^3 and 166.6 μg/m^3 according to the US and Thai recommendations, respectively. Thus, in caulkers, 10/44 specimens of personal air had lead equal to or exceeding 41.7 μg/m^3. Only 1 out of the 44 specimens exceeded 166.6 μg/m^3 and this specimen was collected from a caulker on a day when the work included mingling lead oxide and yang oil with cotton yarn - an activity in which powdered lead oxide is readily dispersed into the air. None of the other personal air collection periods included this task. In general in the two boatyards of this study, each caulker performed the task of mingling lead oxide with cotton yarn about twice a month, each time for approximately 2 to 4 h. This suggests that the activity of mingling yarn and oil with lead oxide is likely to lead to heavy, though sporadic, worker contamination via the inspiratory pathway.

Blood lead levels

Blood lead level is commonly used as an indicator and diagnostic measure of lead exposure in humans[15]. Among the workers of this study, the overall mean BLL of caulkers was 45.2 μg/d*l*, and about 67% of caulkers had BLL exceeding 40 μg/d*l*. These data indicate that serious occupational exposure to lead can occur in caulkers. Accordingly, biological monitoring of lead exposure in caulkers should be considered essential, although it is not at present required in Thailand. It is recommended that Thai regulations be modified to set the minimum level of concern for BLL at 40 μg/d*l*; and if blood monitoring reveals a blood lead level greater than 40 μg/d*l*, the worker should be notified and provided with a medical examination. Annual biological measurement would provide a means of monitoring the effectiveness of improved occupational hygiene in the boatyard.

Factors associated with blood lead levels

Caulkers had higher BLL's than carpenters and technicians. Although most workers worked in the same general area, all tasks of the caulkers bring them into continuous contact with lead oxide, which is reflected in the higher level of personal airborne lead in caulkers than in carpenters. However, there was no evidence of correlation between individual BLL and personal airborne lead measured on 2 consecutive days in this study. This was not an unexpected finding as the long biological half-life of lead means that BLL reflects not only recent but also long-term levels of exposure. The considerable day-to-day fluctuation in personal airborne lead suggests that sampling over 2 d is unlikely to be representative of long-term exposure levels. Furthermore, inspiration of personal airborne lead may not be a major pathway of lead uptake in workers, except during the activity of mingling yarn with lead oxide. Particle size has been reported to have important implications for blood lead values[16], with lead absorption being more closely linked with respirable lead (particle diameter <10 μm) than total airborne lead[17]. Results of particle size analysis of lead oxide used for boat repair reported by Maharachpong[7] indicate that particles of diameter <10 μm account for only about 30% of the total volume. Nevertheless, larger inspired particles could also lead to contamination, via deposition in the upper respiratory tract followed by movement into the pharynx and subsequent swallowing[18]. Thus, at present, the contribution of personal air borne lead to the total lead contamination load of caulkers remains uncertain.

In contrast to the sporadic exposure to high levels of personal air-borne lead during yarn mingling, skin exposure to lead oxide is a daily occurrence for caulkers. Contamination of hands, clothes, hand-tools and working surfaces with lead oxide was clearly evident at each work site. Nevertheless, despite the poor personal hygiene of most workers, no single behavior could be identified as being independently associated with elevated BLL even though it might be expected that lead contamination could occur either by direct hand-to-mouth contact, or indirectly through contamination of hands, foods, drinking water, cigarettes, etc[1, 19]. It is possible that the effects of poor

hygiene behavior are cumulative or that poor hygiene behavior profiles differ among the workers, making it difficult to identify particular contaminating behaviors in a statistical model. Furthermore, direct absorption through the skin cannot be ruled out. It has been shown in other studies that absorption of lead from certain dermally applied inorganic lead compounds can occur, albeit to a lesser extent than from organic lead compounds[20]. It would be of interest to see if the percutaneous absorption of lead from lead oxide is facilitated by its mixture with yang oil in the caulking mixture.

Dykeman (2002) reported that productivity was an important factor contributing to elevated blood lead among radiator workers[21]. The difference in workers' BLL between boatyards number 1 and number 2 in our study might similarly be the result of differences in productivity. In general, the average productivity in boatyard number 2 was higher than that in number 1.

Our model indicates that education level is a factor influencing lead contamination among boat-repair workers. Workers' blood lead was significantly lower among those who had senior primary school or higher level of education. However, the effect of education would appear not to be due to differences in knowledge specifically related to the health hazards of lead. It is possible that the education effect might be mediated via education-related differences in general lifestyle.

Among behaviors potentially related to take-home lead, we found that most of the workers washed only their hands and face before going home but did not clean their shoes. None of the workers took a shower or regularly changed their clothes prior to going home. These poor practices meant that the workers were likely to carry lead contamination elsewhere, potentially exposing their home and families. "Para-occupational" or "take-home" exposures among workers' families may cause lead poisoning in family members[22, 23].

Implications regarding reduction of lead contamination

Despite the generally poor standard of work hygiene, it may not be practical to rapidly develop new technology or change the repair process in a developing country like Thailand to lower BLLs in the boat-repair industry. Thus, we suggest that the tasks and behaviors at work which expose workers to lead should be assessed, and correct work practices and safety behaviors of workers including good personal hygiene be encouraged[24]. Various control measures to decrease BLL of workers should be implemented. Work instruction, training and health education[25, 26], as a fundamental tool can bring about improvements in lead-safe practice and prevention of occupational disease; and such training should be repeated at least annually for each boat-repair worker, as is already implemented among lead-exposed Thai workers in the formal employment sector. In addition, boat-repair workers should be made aware of the risk to their family and encouraged to shower and wash after the work shift to reduce the magnitude of take-home lead.

In addition, boatyard owners should strictly enforce a rule that each worker clean up his workplace after finishing his work each day and that smoking, eating and chewing at the worksite during working hours be forbidden. The owners should provide a separate eating, drinking and smoking area and provide facilities for taking a bath and changing clothes. Finally, boatyard owners should be prepared to measure the level of lead contamination in the workplace and arrange biological lead measures of the workers in order to evaluate the effectiveness of control programs and measures in the working environment.

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