ORIGINAL ARTICLE

Blood lead and erythrocyte protoporphyrin levels in association with smoking and personal hygienic behaviour among lead exposed workers

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Occup Environ Med 2005;**62**:300–303. doi: 10.1136/oem.2004.019513

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Accepted 22 December 2004

Aims: To investigate the effects of smoking and personal hygienic behaviour on blood lead (BPb) and free erythrocyte protoporphyrin levels (FEP) in lead exposed workers.

Methods: Subjects were 105 lead exposed male workers in a battery recycling plant during the years 2000–03. BPb and FEP were measured as part of the ongoing occupational surveillance. Each worker completed a questionnaire for assessment of smoking and four measures of personal hygienic behaviour (glove and mask use, hand and face washing before meals during working hours).

Results: Statistically significant decreases in mean BPb and FEP occurred during the three years. The proportion of BPb reduction in the non-smoking workers was significantly higher (mean 24.3%) than in the smoking workers (15.3%). When the workers were classified into three groups (excellent, good, and poor) based on the four personal hygienic behavioural indicators, the greatest decreases of BPb and FEP were observed in the non-smoking workers of the excellent group.

Conclusions: The consistent use of protection devices and cleanliness at work appeared to contribute to the lowering of BPb and FEP. Cessation of smoking in the workplace was also of importance.

Biomarkers for lead exposure, such as blood lead (BPb) levels, often vary among workers, even in the same workplace. Although inhalation has been considered as the most important route of lead absorption, the airborne lead in the working area does not fully represent the total lead intake of the workers as shown in previous studies.[1 2] When the suspended dust particles are too large to be inhaled in lead exposed workplaces, lead ingestion by contaminated hands or food cannot be neglected as the source of lead intake.[3] Lead absorption through ingestion may be promoted by unhygienic behaviour such as smoking at the workplace without washing hands. Such differences in smoking habits and personal hygiene behaviour have been assumed to be modifiers of lead exposure empirically; however, little evidence has been reported limited to a specific hygienic behaviour—that is, feeding with bare hands, in other countries.[4–6] No quantitative studies have been performed in Japan.

BPb has been generally accepted as the most useful and reliable index of lead intake, reflecting absorbed doses and body burden.[7 8] On the other hand the interaction of lead with enzymatic processes can be sensitively determined by the concentration of free erythrocyte protoporphyrin (FEP) in blood. The accumulation of FEP mainly reflects recent external lead exposure and provides an index for the disturbance of haem synthesis.[9 10] Thus the effectiveness of hygienic behaviour in lead exposed workplaces could be evaluated using both FEP as a sensitive index and BPb as a biomarker of internal lead burden.

The aim of this study was to investigate the influence of smoking and personal hygienic behaviour on lead intake by monitoring BPb and FEP continuously, and assess the contribution of the behavioural factors to the decrease of BPb and FEP in a cohort of Japanese lead exposed workers.

SUBJECTS AND METHODS

The study included 105 lead exposed male workers who had been working in eight departments of distinct operational areas at a battery recycling plant in Japan during 2000–03. The mean age was 47 years (SD 12, range 22–68). The mandatory health check-up was conducted under the Industrial Safety and Health Law in Japan, and levels of BPb and urinary δ-aminolevulinic acid of the workers were regularly monitored by routine medical screening. From 2000, health education for the workers has been promoted by industrial physicians and hygienists in the plant, and the mean level of BPb, which had been at a constant level before 1999, was decreased from 46 to 36 μg/dl between 2000 and 2003. On average, the highest levels of BPb were observed for workers in a smelting area, followed by those in an electrolytic area. Lead in ambient air suspended in the whole workplaces ranged from 0.02 to 0.55 mg/m^3 with an average of 0.19 in 2001, while it ranged from 0.01 to 0.47 mg/m^3 with an average of 0.17 in 2003 ($n = 60$; data for 2000 and 2002 were not available). All workers gave fully informed consent. Ethical approval for the study was given by the committee for labour and safety in the plant.

Blood was collected by venipuncture using sodium heparin as anticoagulant as part of the regular occupational surveillance for prevention of lead poisoning. BPb was analysed by graphite furnace atomic absorption spectrophotometry as described previously;[3] the detection limit was 1.0 μg/dl blood. FEP was determined by a modified Piomelli method using fluorometry after acid extraction.[11 12] For quality control the reference materials were analysed simultaneously; mean values were confirmed within the certified limits.

The workers completed an interviewer administered questionnaire on the same day of the health check-up in 2003, which required information on hygienic behaviour, personal protective equipment, and smoking habits. Smoking habits during working hours were dichotomised as current smokers versus ever (ex-) or never smokers. Those who had stopped smoking before the year 2000 were regarded as ex-smokers. For the responses about the hygienic behavioural indicators

Abbreviations: BPb, blood lead; FEP, free erythrocyte protoporphyrin

Main message

- The consistent use of protection devices and smoking cessation in the workplace appeared to contribute to the lowering of blood lead and erythrocyte protoporphyrin levels.

Policy implication

- Employers should give consideration to the implementation of a programme for anti-smoking and reinforcing hygienic behaviour as well as the proper use of personal protective equipment to reduce lead intake among workers.

of wearing protective masks and gloves, and hand and face washing before meals during on-duty hours, responses were ''always'', ''often'', or ''never''. Answers were confirmed by physician's interview.

In the analysis of the indicators for hygienic behaviour, the answers were scored with 2 points for ''never'', 1 point for ''often'', and 0 points for ''always''. Total points for the four behavioural questions were distributed from 0 to 6 points; there were no scores of 7 or 8 points. Based on the total points, subjects were classified into three groups: group A answering ''always'' for all four questions (total score 0; excellent group); group B answering ''always'' for three and ''often'' for one question (score 1; good group); and group C for the other subjects (score 2 to 6; poor group).

Student's *t* test or Scheffe's test were used to compare the mean values between groups when the normal distribution was assumed by the Shapiro-Wilk test. The Wilcoxon test was used to analyse the differences between the two groups with skewed distributions. The differences in BPb and FEP changes among the behavioural groups were analysed by two way repeated measures analysis of variance (ANOVA), using the model of type II sum-of-squares with F ratios based on the residual mean square error. A level of $p < 0.05$ was regarded as statistically significant. All statistical analyses were performed by using the Statistical Package for the Biosciences (SPBS v9.5).[13]

RESULTS

The number of the current smokers in 2003 was 62 (59% of study subjects); average number of cigarettes smoked per day was 21 (SD 6). The smoking pattern was homogeneous—all the smokers reported that they usually smoked in their working areas when they took a rest during on-duty hours from wearing their personal protective equipment. Figure 1 presents the yearly changes of BPb during 2000–03. Mean BPb decreased significantly in both current smokers ($p = 0.0054$ by one way ANOVA) and ex- or never smokers ($p = 0.0062$), and were significantly different between 2000 and 2003 by Scheffe's test irrespective of smoking habits ($p < 0.05$).

As shown in fig 2, mean FEP also decreased consistently over the three years for both groups of workers ($p < 0.0001$ for current smokers and $p = 0.0178$ for ex- or never smokers, ANOVA); specifically the difference in the values between 2000 and 2003 was significant among the smokers by Scheffe's test ($p = 0.0005$).

Table 1 presents both 2000 and 2003 data of BPb and FEP with statistical comparison between the current smoking and ex- or never smoking workers. Because the baseline values of BPb and FEP in 2000 were relatively higher in the current smokers than in the ex- or never smokers, the proportion of the reduction was calculated as the percentage differences in the values between 2000 and 2003 divided by the value in 2000. The proportion of BPb reduction was significantly higher in the ex- or never smoking workers than in the current smoking workers. The same trend was observed in FEP over the three years, but the proportion of this reduction was not significantly different between the current smoking and ex- or never smoking workers.

Table 2 shows the results of questions for hygienic behaviour with the summarised number of each grouping: A = excellent, B = good, C = poor. As a result of the intensive health education from 2000, a total of 50 (48%) workers constantly wore protective equipment, and washed their hands and faces before eating during working hours every day in 2003.

Table 3 shows mean values of reduction in BPb and FEP during the years 2000–03 (subtracted 2003 value from 2000 value), categorising groups of hygienic behaviour (A = excellent versus C = poor) and smoking status. Ex- or never smoking workers in group A had the highest reduction of both BPb (11.3 μg/dl) and FEP (156 μg/dl RBC), while current smoking workers in group C had the lowest reduction (BPb, 5.1 μg/dl; FEP, 38 μg/dl RBC). Two way analysis of variance (ANOVA) tests revealed that smoking status exerted an independent significant effect on BPb decreases ($F = 2.7$; $p = 0.0084$), but resulted in no significant effects of hygienic

Table 1 Comparison between current smokers and ex- or never smokers in mean levels of BPb (μg/dl) and FEP (μg/dlRBC) in 2000 and 2003

	Current smoker Mean (SE) (n = 62)	Ex- or never smoker Mean (SE) (n = 43)	*p value
BPb in 2000	47.6 (1.8)	43.0 (2.0)	0.0971
BPb in 2003	40.4 (2.0)	32.4 (1.9)	0.0057
% reduction†	15.3 (2.6)	24.3 (2.7)	0.0238
FEP in 2000	268 (27)	196 (24)	0.0624
FEP in 2003	150 (19)	115 (17)	0.1425
% reduction†	37.3 (3.5)	40.7 (3.4)	0.5131

*t test.
†Percentage was calculated by subtracting each 2000 value from 2003 value divided by 2000 value (mean (SE)).

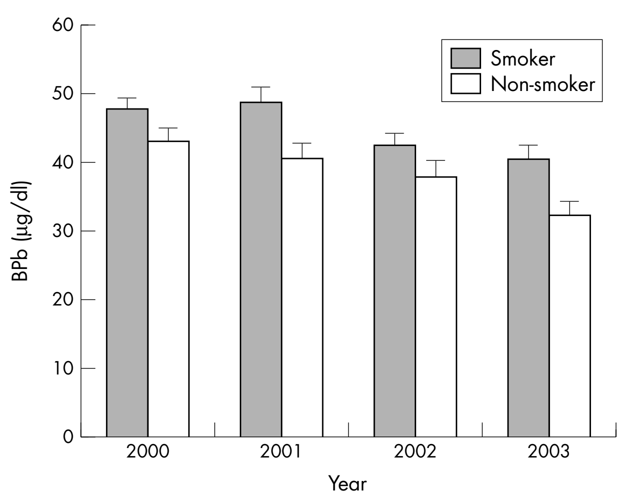

Figure 1 Yearly changes of BPb during 2000–03 among the current smoking and ex- or never smoking workers.

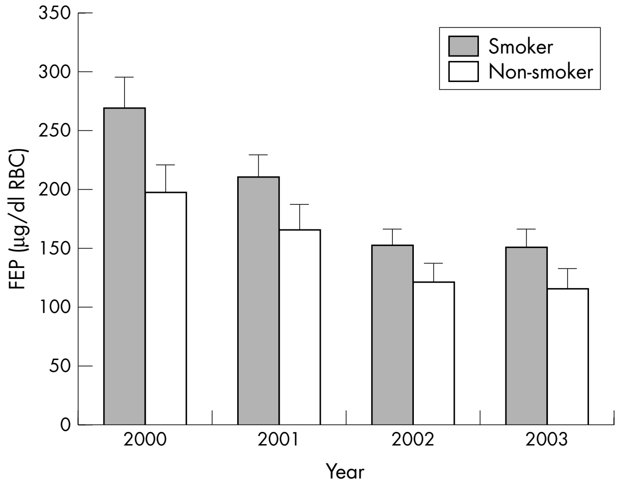

Figure 2 Yearly changes of FEP during 2000–03 among the current smoking and ex- or never smoking workers.

behavioural group ($p = 0.717$) or interaction effect between smoking and hygienic behavioural groups ($p = 0.584$).

DISCUSSION

The workers of the plant had received intensive health education since 2000 and had made some progress in reducing the levels of BPb and FEP up to 2003. In this study, the magnitude of these reductions was higher in ex- or never smokers than in current smokers. The proportion of ''excellent'' hygienic workers (group A) among the current smokers was the same as that among the ex- or never smokers (30/62 (48%) versus 20/43 (47%)). Although there may be an overestimation for the self-reported ''excellent'' rating, it is unlikely to occur depending on their smoking status. In most workers who smoked, the influence of excellent hygienic behaviour could not be reflected; there still seems considerable room for improvement of BPb levels independent of ambient air levels of lead. Intervention over workers' behaviour should be devoted to increasing workers' knowledge of smoking hazards and promoting smoking cessation in the workplace.

Although the reduction of BPb was not as distinct as that in FEP on average, the BPb differences between 2000 and 2003 were statistically significant. In spite of the health education, FEP in some of the workers increased retrogressively over the three years, although the individual data are not shown in the present study. FEP reflects recent exposure sensitively, with the result that its value might fluctuate temporarily with inter- and intra-individual factors. BPb reflects body burden in proportion to the lead storage in the skeletal system (biological half time 1–10 months). Therefore BPb may be a more reliable indicator for biological monitoring in long term interventions such as this study.

It has been recognised that good equipment and cleanliness in the workplace will contribute to reduce the exposure to toxic substances. Our results suggest that no smoking in the workplace contributed to the improvement of BPb. In contrast, even the excellent hygienic behaviour (wearing masks and gloves daily and washing hands and face before every meals) had no effect on BPb if the workers smoke. A positive relation between smoking and BPb levels has been found in some studies.[4 14–16] The mechanisms could be mainly attributed to the contamination of cigarettes by workers' fingers,[4 14] and partially to the impairment of lung clearance mechanisms by smoking.[15 16] Smoking may act as a vector for lead to be transferred from face and hand to mouth.[3] It is possible to ingest lead via contaminated cigarettes and fingers when workers smoke or simply touch their mouth. Thus the restriction of smoking with the promotion of hand washing could reduce the unnecessary uptake of lead in the workplace.

Besides smoking, lead intake might be influenced by the hygienic behaviour of workers. In the excellent hygienic behaviour group, their FEP tended to be lower over the three years compared with the poor behaviour group. Although the results showed no significant difference, possibly due to the small number of the poor group ($n = 15$ for current smokers and $n = 7$ for ex- or never smokers), the hygienic behaviour seemed to modify the biological monitoring parameters of lead, especially in ex- or never smoking workers. It was shown in previous studies that workers with higher levels of surface lead on their hands had higher BPb,[17] and the frequency of hand-mouth or hand-nose touching became the significant modifier of the BPb.[5] In another study the habit of eating with bare hands and fingers explained the variance of 40% in BPb among lead-acid battery workers.[6] We support the idea that the differences in hygienic behaviour at work explain the degree of the reduction of BPb and FEP to some extent. However, the data of lead-in-air levels (APb) were available only in 2001 and 2003, thus our study has limitations in that the results could not be evaluated because of the possible confounding effect of APb during 2000–03. Further study with personal air sampling would be needed to estimate the contribution of APb to the observed findings.

Elemental lead and inorganic lead compounds are absorbed through inhalation or ingestion. Pulmonary absorption is efficient, particularly if particle diameter is <10 µm. For diameters >10 µm, lead enters the body by ingestion. Thus ingestion related behaviour may have an important impact on biological monitoring parameters of lead. For example, the workers who smoked in their workplace could

Table 2 Frequency of personal hygienic behaviour and number in each hygienic group

Frequency	Always	Often	Never
During working hours			
Wearing masks	97 (92%)	7 (7)	1 (1)
Wearing gloves	88 (84)	14 (13)	3 (4)
Before eating during on-duty hours			
Washing hands	98 (93)	6 (6)	1 (1)
Washing face	55 (52)	37 (35)	13 (12)
Hygienic grouping	**A (excellent)**	**B (good)**	**C (poor)**
Summary of the above 4	Always = all 4 n = 50 (48)	Always = 3, Often = 1 n = 33 (31)	Others n = 22 (21)
Number of current smokers within each group category	30 (60)	17 (52)	15 (68)

Table 3 Mean (SE) values of reduction in BPb and FEP between 2000 and 2003 stratified by smoking and hygienic behaviour groups

	Hygienic behaviour	Subtraction 2003 data from 2000 data		
		n	BPb* (µg/dl)	FEP (µg/dl RBC)
Ex- or never smokers	Group A	20	11.3 (2.1)	156 (39)
	Group C	7	8.9 (2.9)	75 (28)
Smokers	Group A	30	5.1 (1.4)	73 (16)
	Group C	15	5.1 (1.9)	38 (11)

*Two way analysis of variance (ANOVA) showed a significant difference between smokers and ex- or never smokers ($p = 0.0084$), but no significant variation between A (hygienic excellent group) and C (poor group) ($p > 0.05$).

have picked up dust containing lead from their contaminated cigarettes and/or work clothes with their naked hands. The ex- or never smoking workers who keep their hands clean could reduce hand-to-mouth transfers of lead. Although generalisation to all workers is not justified, measurement of anti-smoking and hygienic behaviour by a routine checklist may be helpful to alleviate the absorption of lead through hand and mouth contamination.

In conclusion, the findings suggest that smoking behaviour of workers increases the risk of lead exposure in the workplace. Employers should consider not only engineering controls or replacement of processes, but also personal health education to prevent lead exposure among the workers. The implementation of a programme for anti-smoking and reinforcing hygienic behaviour as well as the proper use of personal protective equipment could be effective for the reduction of lead intake, especially for workers who smoke frequently.

ACKNOWLEDGEMENTS

The authors thank Drs Katsuyuki Murata, Miwako Dakeishi, and Toyoto Iwata for their assistance during the field work. This study was supported by grant-in-aids for scientific research from the Japan Ministry of Education, Science and Culture.

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Competing interests: the authors declare they have no competing financial interests

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