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The association between lead contamination on the hand and blood lead concentration: A workplace application of the sodium sulphide (Na_2S) test

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Abstract

Objectives: Lead is one of the major causes of workplace poisoning and lead contamination on skin is a possible route of lead absorption. Using a colourimetric method with sodium sulphide (Na_2S), we examined whether the lead on skin represents longer-term lead exposure.
Methods: This cross-sectional study of 119 lead-handling workers in a battery recycling plant in Japan was conducted in July 2004. The main outcome measure was skin-colour darkening on the workers' hands, visualised by wetting the seemingly clean hands of the workers with 1% Na_2S solution (128 mmol/L): the Na_2S test. This study then examined the relationships between the Na_2S test results and workers' blood lead concentration (BLC) and hygiene activities.
Results: The Na_2S test produced skin-colour darkening of the hands of 92 (77%) of the lead workers, although 88 of them had washed their hands with soap and 50 had bathed before taking the test. In the bivariate analyses, a positive result in the Na_2S test was associated with not washing hands ($p=0.009$), not bathing ($p=0.061$), and a higher BLC ($p=0.008$). The association between the results of the Na_2S test and BLC was still significant in the multivariate linear regression analysis adjusted for age and hand washing ($p<0.001$).
Conclusions: Lead contamination on workers' hands, otherwise unapparent, was clearly demonstrated by the Na_2S test. The result of this test was associated with BLC in addition to the hygiene activities after the last work with lead. As the lead contamination on the hand is persistent, simply encouraging hand washing may not be sufficient to reduce lead intake into body.

Keywords: Lead; Hot springs; Sulphur compounds; Health education; Occupational exposure; Monitoring; Hand contamination

1. Introduction

Lead is one of the major causes of workplace poisoning (Basaran and Undeger, 2000; Al-Neamy et al., 2001; Bener et al., 2001; Hsiao et al., 2001; Danadevi et

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al., 2003). To minimize lead exposure, various methods for monitoring lead in bone (Brito et al., 2000), whole blood and urine (Makino et al., 2000), and erythrocytes (Kim et al., 2002) have been introduced. In Japan, the Ordinance on the Prevention of Lead Poisoning mandates that all workers handling lead have health check-ups twice a year to monitor blood lead concentrations (BLC) and urinary delta-aminolevulinic acid (Ogata, 1993). Despite all the efforts, lead exposure is still high in many workplaces (Jakubowski et al., 1998; Karita et al., 2000; Makino et al., 2000; Kim et al., 2002; Suwansaksri et al., 2002; Pierre et al., 2002).

Lead contamination on the skin is a possible route of lead absorption (Ulenbelt et al., 1990; Far et al., 1993; Askin and Volkmann, 1997; Karita et al., 1997; Hwang et al., 2000; Nuwayhid et al., 2001). Lead workers may absorb lead by ingestion either via hand-to-mouth activity or by eating (Lerner and Hogan, 1985). Hwang et al. (2000) found that the BLC was related to lead contamination on workers' lips. Smoking lead-contaminated cigarettes or touching the lips with contaminated hands is associated with lead absorption while smoking (Nuwayhid et al., 2001). Hence, in practice, lead-handling workers are advised to improve their hygiene by refraining from smoking, washing their face and hands, and bathing after work.

Bathing is the preferred way to remove lead from the skin. In addition, in Japan, spa bathing is a very popular leisure activity, and Japanese customarily soak in large, communal hot springs. Nonetheless, the lead workers at a battery-recycling plant were reluctant to bath in spas because whenever they bathed in a nearby spa, which was rich in sulphide ions, their skin took on a dark colour and appeared filthy, no matter how carefully they washed beforehand. This led us to hypothesise that lead on the workers' skin reacted with sulphide ions, producing lead sulphide, which made their skin appear darker, and that lead contamination was too persistent to be removed by usual hygiene activities.

In 1985, Lerner and Hogan (1985) applied Na_2S to lead-workers' hands that were visibly clean and found that a number of the lead-workers' hands were contaminated with lead, even when the workers had no contact with lead on the day of their test. This implied that the lead contamination detected by sodium sulphide (Na_2S) was more than the current level of hand contamination. However, they failed to discuss the possible association between hand contamination and the BLC or hygiene activities of lead workers.

Learning from the experiment of Lerner and Hogan (1985), we modified the Na_2S test and asked workers to dip the ulnar halves of both hands in 1% (128

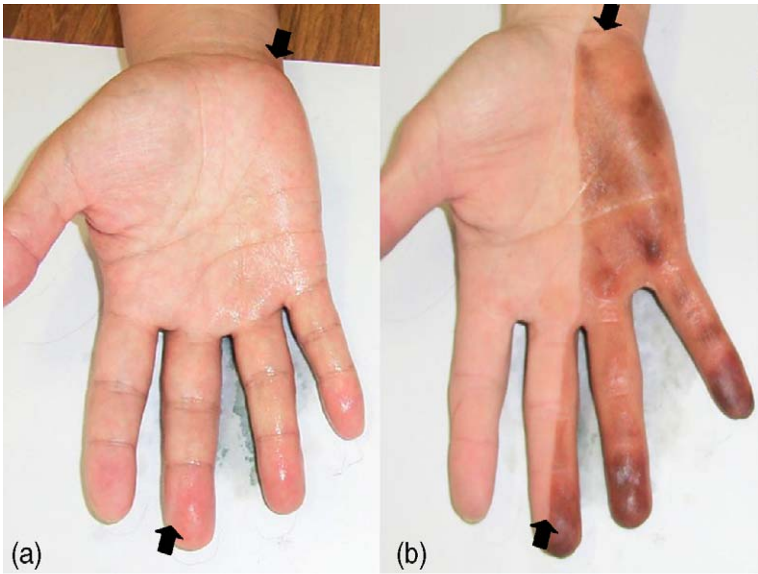

Fig. 1. The hands of lead workers after dipping in Na_2S solution. The line between the arrows is the border of the area dipped in 1% sodium sulphide solution. The ulnar sides of both hands were stained. (a) A hand classified as (−). (b) A hand classified as (++).

mmol/L) Na_2S solution. Then, the hands were photographed. By detecting the border between the unstained area and dark marking, a physician blind to the workers' BLC graded the change in hand colour in the photograph as (−) border absent, (±) border partly present, (+) border obvious, and (++) border obvious with marked darkening. Fig. 1 shows examples of the Na_2S test result; the picture on the left shows a hand classified as (−), and the picture on the right shows a hand classified as (++).

Based on the story of spa bathing and the findings of Lerner and Hogan (1985), we speculated that the lead contamination detected by Na_2S represents both occasional lead contamination attached to the skin surface and longer-term lead exposure for a certain period of time. Here, the former was correlated with hygiene activities immediately after working with lead, and the latter was correlated to the BLC. If the occasional lead contamination was controlled, then the result of the Na_2S test would reflect longer-term lead exposure. In this study, we conducted the Na_2S test at the plant where lead workers complained that their skin changed colour in the local spa and assessed the relationship between the results of the Na_2S test and the BLC, controlling for the workers' hygiene activities.

2. Materials and methods

2.1. Subjects and setting

This study was performed in a plant where lead batteries are recycled. There were 470 employees in total, and 163 of them (162 male and 1 female) engaged in collecting lead electrodes from batteries, smelting them, making lead metal tape for new batteries, and making oil paint from lead powder. In the lead workplace, the air lead concentrations ranged from 0.03 to 0.81 mg/m^3 (measured in July 2004 using high- and low-volume sampling); other compounds involved in sulfuration reactions, such as iron, copper, and zinc, were scarce. Most of the lead workers were manual labourers; a few were administrative staff. Of these workers, we excluded the administrative staff (n=26; 17%) and those making lead paint (n=6; 4%), since they did not handle lead. We also excluded 12 other lead workers (11 male and 1 female) who did not take the Na_2S test. Ultimately, 119 lead workers were enrolled in this study.

2.2. Blood lead concentration and the Na_2S test

In June 2004, BLC was measured as part of the workers' regular health check-up. In July 2004, the Na_2S test and an additional questionnaire survey were administered in the plant. The BLC was analyzed using graphite furnace atomic absorption spectrophotometry, as described elsewhere (Karita et al., 2005), and the detection limit was 0.048 μmol/L (1.0 μg/dL) blood. Quality control was assessed by measuring reference materials simultaneously, which confirmed that the mean values were within the certified limits.

As the concentration of the Na_2S solution increases, the change in colour produced by lead sulphide should become more distinct because the test is based on a colourimetric method; however, if the solution concentration exceeds 8.0%, an allergic reaction can occur on the skin (Lerner and Hogan, 1985). We chose a Na_2S solution concentration of 1.0% (128 mmol/L) based on Lerner and Hogan (1985), who used 0.5%–1.5% Na_2S solutions to detect lead contamination on the hand. When Na_2S solution contacts air, H_2S gas is produced immediately. To prevent H_2S poisoning, we performed the Na_2S test in a large auditorium, periodically ventilating it with fresh air.

Previous studies have ascertained that Na_2S solution could make apparent previously invisible lead contamination on skin. As Taylor et al. (2004) reported, visibly clean skin was still contaminated with lead in workers who were exposed to high lead levels. Lerner and Hogan (1985) demonstrated that Na_2S solution reacted with lead, producing a dark colour on the skin. In the plant, where the workers' BLC was high, other sources of the sulfuration reaction were scarce. Therefore, the application of Na_2S solution was deemed a valid method for quantifying the level of lead contamination on lead-workers' hands. Moreover, five subjects who scored (++) in the Na_2S test scored the same result (++) six months later, demonstrating the reliability of the test.

2.3. Questionnaire

Information on smoking habits and hygiene activities was obtained from a self-administered

Table 1
Results of Na_2S testing of 119 lead workers

Result of the Na_2S test	$n=119$	%
(−)	27	23%
(±)	10	8%
(+)	67	56%
(++)	15	13%

questionnaire completed by all 119 subjects on the day of the Na_2S test. Smoking habits were classified as current smoker who smokes while working with lead, current smoker who does not smoke while working with lead, and non-smoker. Workers were also asked whether they washed their hands and bathed after the last work with lead. In an additional interview, a physician clarified ambiguous answers and asked about the potential of an allergic reaction to Na_2S.

2.4. Analysis

For the Na_2S test, we graded the level of lead contamination on the subjects' hands using four categories: (−), (±), (+), and (++). The results of Na_2S test were compared using Fisher's exact test according to the hygiene activities 'hand washing' with soap or 'bathing' after the last work with lead. Analysis of variance was then used to examine the relationship between the results of the Na_2S test and age, length of lead work, BLC, smoking habit, and hygiene activities. Using a linear regression, the relationship between the Na_2S test and BLC results was adjusted for age and hand washing. We did not introduce bathing or length of lead work into the model due to concerns over colinearity and did not include smoking habit due to lack of relevance to the Na_2S test result ($p>0.10$). A level of $p<0.05$ was regarded as statistically significant. We performed all the statistical analyses using SAS version 8.2.

2.5. Ethics approval

This study was performed as a part of routine health and safety activity conducted in the plant, which the authors did under contract with the company in accordance with the Ordinance on the Prevention of Lead Poisoning. The Hygiene and Safety Committee of the plant approved the study protocol.

3. Results

The subjects ranged in age from 21 to 68 (mean ± S.D.: 46.3 ± 12.8) years and had 0.2 to 40 (10.8 ± 9.3) years of lead-handling work experience. Overall, the BLC ranged from 0.43 to 3.91 (1.89 ± 0.62) μmol/L. Ninety-one subjects (76%) were current smokers. Sixty-four smoked at the work with lead, while 27 did not. Before taking the Na_2S test, 88 subjects had washed their hands with soap, and 50 subjects had bathed since the last work with lead. Table 1 shows the results of the Na_2S test. The test produced skin darkening in 77% of the hands of the lead workers.

Table 2 shows the relationship between hand washing and bathing after the last work with lead and the results of the Na_2S test. Those who washed their hands with soap before taking the test had cleaner hands than those who did not ($p=0.009$). In addition, those who bathed before taking the test had cleaner hands at a marginally significant level than those who did not ($p=0.061$). The result of the Na_2S test was not associated with age, length of lead-work experience, or smoking ($p=0.691$, 0.221, and 0.325, respectively).

Table 3 shows the relationships between the results of the Na_2S test, smoking, and hygiene activities before taking the Na_2S test and the BLC. The BLC of the workers whose hands were classified as (−), (±), (+), and (++) were 1.59 ± 0.60, 1.84 ± 0.59, 1.93 ± 0.61, and 2.24 ± 0.56 ìmol/L, respectively. BLC was positively associated with the level of lead contamination detected by the Na_2S test ($p=0.008$). Other variables of smoking status, hand washing, or bathing were not associated with BLC ($p=0.892$,

Table 2
Relationship between the hygiene activities after last working with lead and the results of the Na_2S test

$n=119$	Result of Na_2S test								p value[a]
	(−)		(±)		(+)		(++)		
Hand washing	n	%	n	%	n	%	n	%	0.009
Yes ($n=88$)	25	28	8	9	47	54	8	9	
No ($n=25$)	1	4	2	8	15	60	7	28	
Bathing									0.061
Yes ($n=50$)	15	30	7	14	23	46	5	10	
No ($n=69$)	12	17	3	4	44	64	10	15	

Missing values: 6 for hand washing.
[a] Compared using Fisher's exact test.

Table 3
Relationships between the results of the Na_2S test, smoking, and hygiene activities before taking the Na_2S test and the blood lead concentration

$n=119$	Blood lead concentration, μmol/L Mean ± S.D.	P value[a]
Result of the Na_2S test		0.008
(−) $n=27$	1.59 ± 0.60	
(±) $n=10$	1.84 ± 0.59	
(+) $n=67$	1.93 ± 0.61	
(++) $n=15$	2.24 ± 0.56	
Smoking habit		0.892
Smokes while working $n=64$	1.95 ± 0.67	
Does not smoke while working $n=27$	1.97 ± 0.53	
Non-smoker $n=28$	1.67 ± 0.56	
Hand washing		0.818
Yes $n=88$	1.88 ± 0.54	
No $n=25$	1.92 ± 0.66	
Bathing		0.269
Yes $n=50$	1.96 ± 0.65	
No $n=69$	1.83 ± 0.60	

S.D.: standard deviation. Missing values: 6 for hand washing.
[a] Compared using analysis of variance.

0.818, and 0.269, respectively). When the results of the Na_2S test, BLC, age, and hand washing were applied to the multivariate model (Table 4), Na_2S test results were significantly associated with BLC and hand washing ($p<0.005$ and $p=0.002$, respectively); stratification by hand washing did not affect the association between Na_2S test and BLC results.

4. Discussion

Na_2S produced skin darkening in a majority of the hands of lead-handling workers, although most of the workers took the test after washing their hands with soap or bathing. The extent of the colour change was positively associated with their BLC, even after adjusting for their hygiene activities.

After dipping their hands in the Na_2S solution, the colour of a majority of the workers' hands, which had looked clean, changed to brown. The apparent dark deposits consisted of lead sulphide, since other causes of the sulfuration reaction were scarce in the plant. This result supports the finding of Lerner and Hogan (1985), who found that Na_2S testing revealed invisible lead contamination on the hands of a number of workers, even those who reported no contact with lead on the day of the test.

The Na_2S test was based on simple colourimetric method, so it is easy to detect the level of lead contamination. In the lead-handling workers, lead contamination, as detected by the Na_2S test, was positively associated with BLC. This means that the result of the Na_2S test represented both lead on the skin surface and lead in the inner or deep skin, as hand contamination persisted in workers who washed their hands or bathed after working with lead. Therefore, the association between the results of the Na_2S test and BLC suggests that the Na_2S test is a simple, useful method for assessing the level of workers' lead exposure over a certain period of time.

Our results also suggest that a substantial amount of lead contamination remains in the deep skin, while hygiene activities after lead work removed the lead on the skin surface. We found that those who washed their hands or bathed before taking the Na_2S test had better results in the Na_2S test. Nevertheless, even after adjusting for these hygiene activities, the results of the Na_2S test related to the BLC. Taylor et al. (2004) reported that wipe samples of visibly clean earlobes ($n=123$) still contained up to 300 μg of lead. It is likely difficult to remove remaining lead contamination in the deep skin no matter how diligently lead workers wash.

There may be several underlying mechanisms that explain the persistence of lead in the deep skin: external lead may permeate from the surface to the deep

Table 4
Multivariate adjusted results for the results of the Na_2S test

	β	p value[a]
All ($n=112$)[b]		
BLC, μmol/L	0.48	<0.001
Hand washing (yes = 1, no = 0)	−0.68	0.002
Hand washing: yes ($n=88$)[c]		
BLC, μmol/L	0.46	0.005
Hand washing: no ($n=25$)[c]		
BLC, μmol/L	0.55	0.048

BLC: blood lead concentration. Missing values: 1 for age and 6 for hand washing.
[a] These models take the result of the Na_2S test as an ordinary variable (negative = 0, suspicious = 1, positive = 2, and strongly positive = 3).
[b] Adjusted for age, BLC, and hand washing.
[c] Adjusted for age and BLC.

skin or blood lead may infiltrate to skin. In addition, Omokhodion and Howard (1991) observed that the sweat lead concentration was five to ten times higher than the blood lead concentration. Therefore, lead in sweat glands may play a vital role in the process of lead absorption and exudation. We were unable to identify the cause of lead contamination on hands in this study but plan to investigate measures for preventing lead contamination and for undertaking lead decontamination to identify the mechanism causing lead contamination on the hands.

The colourimetric Na_2S test involved subjective grading, making it a limitation of this study. An objective procedure for grading the colour of the lead sulphide deposits might produce clearer results. In addition, light-coloured people may receive higher grades in the Na_2S test, so variance in the colourimetric assessment due to skin colour differences might also be a limitation of this study. However, assessments were made for the palmer surfaces, where initial skin colour differences were small.

We could not determine the origin of lead in the deep skin. If blood lead infiltrates the skin or sweat contaminates the skin, the Na_2S test could be treated as an alternative measure of the lead concentration in the body. Conversely, if external lead permeates the deep skin or lead is deposited in sweat glands, the Na_2S test gives a summary of recent exposure over an undetermined period of time.

Finally, other predisposing factors affecting the levels of lead contamination, such as compliance with hygiene behaviours or lead contamination at home, were not investigated.

In conclusion, lead contamination on workers' hands, otherwise unapparent, was clearly demonstrated by dipping the hands in Na_2S solution. The results of this procedure were associated with BLC in addition to the hygiene activities after the last work with lead. As the lead contamination on the hand is persistent, simply encouraging hand washing may not be sufficient to reduce lead intake into body.

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