Hand Self-Wiping Protocol for the Investigation of Lead Exposure in the Workplace

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The purpose of this project was to develop and validate a hand wiping protocol to be used by occupational hygienists, scientists, or other competent persons, measuring skin exposure to lead in workplaces. Inadvertent lead ingestion is likely to occur once the hands of employees have become contaminated. Ideally, a hand wiping protocol should maximize the recovery of lead-based residues present on employees' hands in a cost-effective and reproducible manner. This article describes an effective and practical hand wiping procedure.

Here, two standardized protocols (A and B) are designed. Protocol A is a self-wiping protocol requiring employees to wipe their own hands using four separate and successive wipes. Protocol B involves a scientist wiping the hands of employees using four wipes, followed by employees self-wiping their hands using two wipes (total of six wipes). Both protocols are defined by four wipe passes over each hand using Ghost wipes.

Because this study took place in the workplace rather than in a simulated laboratory environment, only the relative (i.e., not absolute) removal efficiencies of the hand wiping protocols have been assessed.

The two protocols were first evaluated at a double glazing panel manufacturing site where between 248 μg and 4544 μg of lead was found on employees' hands. A statistical analysis (t-test) on the mean relative lead levels recovered in the first parts of the protocols indicated that Protocol A was more efficient than Protocol B (73% for Protocol A vs. 65% for Protocol B). The relative recovery of the combined first two passes against the combined first three passes also confirmed the greater efficiency of Protocol A (83.3% for Protocol A vs. 76.5% for Protocol B). However, lead levels recovered on the fourth pass remain significant at more than 10% of the total recovered loadings. Nonetheless, Protocol A was preferred and further evaluated at a lead battery manufacturing site where between 149 μg and 18,784 μg of lead was found on employees' hands.

Keywords lead exposure, lead ingestion, skin contamination, wiping protocol

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INTRODUCTION

The importance of quantifying the amount of hazardous substances accumulating on the skin of workers relates to the ability to evaluate the potential for exposure by ingestion and skin absorption. However, hazardous substances may also cause localized skin health issues such as occupational dermatitis. Inadvertent ingestion is often indirectly evaluated by combining biological monitoring (an evaluation of all routes of exposure) and personal air sampling measurements (an evaluation of exposure by inhalation). A poor correlation between the biological monitoring and air sampling measurements might be attributed to potential exposure by ingestion if it can be assumed that dermal absorption is negligible.

Occupational exposure to lead is likely to occur through inhalation and inadvertent ingestion. Lead ingestion has been identified as a significant route of exposure in a number of occupational settings.⁽¹⁻³⁾ A simple conceptual model for inadvertent ingestion was proposed by Cherrie et al.⁽³⁾ It describes the potential transfer of contaminants from the source to workplace surfaces, the hands, the facial region around the mouth, and the mouth itself.

A number of skin sampling techniques were originally developed for the quantification of body exposure to

pesticides.⁽⁴⁻⁶⁾ However, the most common methods routinely used by occupational hygiene professionals are skin wash and wet wipes applied to workers' hands.⁽⁷⁾ Skin samples collected close to the mouth are likely to provide a better estimation of the likely exposure by ingestion than hand samples.⁽⁸⁾ However, wiping the hands is probably felt, by most workers, less intrusive than wiping the lips.

Wipe and wash sampling techniques rely on the combined actions of the mechanical forces generated by rubbing the skin and the wetting of the residues by a washing solution. They are appropriate for use when considering evaluating the contamination of the skin by dust residues. The output is a mass of substance per unit of surface area (i.e., one or both hands) at the time of sampling. This output remains difficult to interpret by itself as a measure of actual exposure. Indeed, personal hygiene and behavior are additional determinants of workers exposure and uptake that remain difficult to appraise.

Wipe sampling might not always be as effective as hand washing⁽⁷⁾ but it is easier to deploy through the workplace with minimal disruption to the processes being investigated. The recovery efficiency of wipe sampling is dependent on the type of wipes used. A selection of commercially available pre-wetted skin wipes (Palintest from Palintest USA, Erlanger, KY; Wash'n Dri from Colgate-Palmolive, New York, NY; and Ghost wipes from Environmental Express, Charleston, SC) were evaluated by Boeniger⁽⁹⁾ for their low lead background concentration, acceptable analyte recovery, size, and resistance to tear. The recovery efficiency from the hands of a single subject was also evaluated using four successive wipes applied to the palms of the hands for 30 sec. The hands were originally contaminated by rubbing lead oxide and corn starch to the palms. This is a very limited study as only a single individual self-wiped his hands and no details of the wiping pattern were provided.

Although the recovery efficiency of wiping surfaces is specified in ASTM Method E1792-03,⁽¹⁰⁾ there is currently no description of a reference wiping pattern applicable to the skin. There is little information disclosed in the scientific literature on the "best" way to wipe the hands of workers in an efficient, cost effective and reproducible manner. The efficiency of wipe media at recovering lead dust and residues from the skin, including the hands, has been investigated but few details are available on the wiping patterns used or on the relative merit of different wiping protocols. For example, Boeniger⁽⁹⁾ used four consecutive wipes to sample both hands wiping for 30 sec each time but does not provide explicit evidence of the wiping pattern used. Geno et al.⁽¹¹⁾ used a sponge to perform a general wipe of the hands followed by a more thorough wiping of the fingers and palms using a second sponge. Fenske et al.⁽¹²⁾ used three cotton pads for wiping separately the palms, the backs and the fingers of the hands. Gorman Ng et al.⁽¹³⁾ used three skin wipes for the back of the hands and another three for the hand and finger contour using two passes (i.e., passing over the skin twice).

Hence, here two hand wiping protocols are proposed for the evaluation of the potential for lead ingestion. A consistent, but labor-intensive, method of a scientist wiping a subject's hands in a strict protocol is compared to a quicker method whereby the subjects themselves wipe their own hands after being given a simple demonstration by a scientist. The comparison is based on the relative recovery (i.e., not absolute) efficiencies of the two methods applied in a real work environment.

Self-wiping is the hand sampling protocol that is more practical, time efficient, and less costly than wiping by a scientist. Wipes and sampling tubes can be prepared in advance of a visit and distributed to the employees on the day. After a short initial demonstration, employees are able to self-wipe their hands without excessive supervision. Groups of employees can be supervised if necessary when wiping their own hands at particular times during the work shift. As self-wiping is the most practical, it is necessary to demonstrate that it is at least as consistent and efficient as scientist-wiping with recovering lead from the hands of employees. The hand wiping protocol selected could be used by occupational hygienists, scientists, or other competent persons, for the measurement of skin exposure to lead in workplaces. This hand wiping protocol may also be applied for the assessment of skin exposure to other appropriate substances used in the workplace.

METHODOLOGY

Wipe Selection

Boeniger⁽⁹⁾ reported that the mean recovery after the first wipe ranged from 52% (Ghost) up to 63% (Wash'n Dri), while the total mean recovery for the successive four wipes were found to range between 70% (Ghost) and 79% (Palintest). The Ghost wipe recoveries were slightly lower than the two other wipe brands although at high loading the difference was not statistically significant. None of the wipe brands tested were able to recover at least 75% of the applied dose after the first wipe (a minimum acceptable recovery for smooth surfaces (not skin)) as specified in ASTM Method E1792-03.⁽¹⁰⁾ In the case of the Ghost wipes, the total recovery did not exceed 71% even after combining the four consecutive wipes.

The "absolute" dust recovery from hands using Ghost wipes will not be further assessed in this study; the "relative" recovery of lead from hands will be used as a more practical parameter of estimating wiping efficiency in the workplace. Boeniger⁽⁹⁾ reported that the relative recovery of the first wipe compared to the first plus second wipes was typically greater than 75% (between 82% and 87% for Ghost wipes). These results indicate a moderately efficient sampling method which was based on an earlier version of the same ASTM Method (E1792-96a⁽¹⁴⁾). Among the wipe brands tested, the Ghost wipes made of tougher material offered a greater resistance to tears.

Here, Ghost wipes are selected for sampling lead contamination on hands based on in-house experience of using these

FIGURE 1. Locations and directions of wiping on the back and palm of the left hand.

and other wipes, their removal performance from skin, low background level of lead, and their greater tear resistance.

Chemical Analysis

Wet chemistry analysis of elemental lead (Pb) on Ghost wipes was undertaken in accordance with procedures described in BS ISO 15202-3.⁽¹⁵⁾ Bottled wipes were digested in nitric acid at 95°C for 1 hr followed by analysis for lead by inductively coupled plasma–atomic emission spectroscopy (ICP-AES). The extraction efficiency was evaluated by spiking blank Ghost wipes with a known amount of lead pipetted from a standard solution. The results are considered accurate to $\pm 10\%$ (or $\pm 1 \mu\text{g}$, whichever is the greater).

Hand Wiping Pattern

A hand wiping pattern was developed in-house. It requires the skin to be wiped from the heel of the hands above the wrist (above wide black tape in Figure 1) up to the fingertips. The left and right hands are wiped following the same pattern. Three distinct parts of the hands are wiped consecutively to ensure consistency and that the hands are fully wiped. The wiping steps, locations, and directions described thereafter apply to both hands but are shown in Figure 1 for the left hand only.

- Step 1: The backs of the hands from the wrist to the base of the fingers (knuckles) are wiped. Five strokes are used starting from the base of each black arrow and ending towards the arrow head.
- Step 2: The palms of the hands are similarly wiped.
- Step 3: The fingers and thumbs, including the finger web areas and sides of the fingers, are wiped in the direction of the grey arrows.
- Step 4: The fingertips are wiped (locations shown by white arrows) and the wipe bottled.

Hand Wiping Protocols

Double Glazing Panel Manufacturing Site

Two hand sampling protocols based on this hand wiping pattern were tested on eight employees of a double glazing panel manufacturer. These employees positioned self-adhesive metal lead tapes on glass to simulate leaded glass windows. They were willing to take part in the study as part of their normal work and no ethics approval was required. A scientist demonstrated to the participants how to wipe their hands following the prescribed wiping pattern described in Figure 1 and the sampling protocols described here. Five employees followed Protocol A and three followed Protocol B. The protocols do not require any pre-cleaning of the hands.

Protocol A consists of an employee self-wiping both hands using two consecutive Ghost wipes, and then repeating the process (total of four Ghost wipes used). In effect, Protocol A simply requires an employee to self-wipe both hands four times using the wiping pattern presented in Figure 1 and detailed in Figure 2.

Protocol B consists of a scientist wiping each employee's hand twice using four consecutive Ghost wipes, followed by the employee self-wiping both hands using two consecutive Ghost wipes (a total of six Ghost wipes used). A new pair of nitrile gloves is worn by the scientist for each employee sampled. Details of Protocol B are presented in Figure 3.

Employees were under constant supervision during hand sampling. It should be noted that each hand is wiped twice in the first half of both protocols by different methods, but the second half of Protocol A is identical to the second half of Protocol B.

Employees self-wiping following Protocol A were provided with a labelled re-sealable plastic bag containing four Ghost wipes and four 50 mL screw top tubes labelled 1–4. Employees were asked to bottle each wipe immediately after use in

the numbered tube corresponding to the order the wipe was taken.

Employees that had their hands wiped following Protocol B were provided with a labelled re-sealable plastic bag containing six Ghost wipes and six 50 mL screw top tubes labelled 1–6. Each wipe was bottled immediately after use in the numbered tube corresponding to the order the wipe was taken.

All bottled wipes were replaced in the re-sealable plastic bag provided with employee's name, date, and time of sampling recorded on the label.

Lead Battery Manufacturing Site

The levels of lead contamination on the hands of 23 employees working at a lead battery manufacturing site were also estimated using hand wipes. The employees volunteered to take part in this study as part of their normal work and no ethics approval was required. They were asked to wipe their hands following Protocol A exclusively. They self-wiped on three occasions during their work shifts: at the beginning of the shift (before work started) or at the end of the shift (after taking a shower but before going home) and twice during the shift either before or after a break. Volunteers worked in

TABLE I. Differences between Protocols A and B

	Protocol A			Protocol B		
	Wipe number	Pass number			Pass number	Wipe Number
Part 1	1	1	Self-wipe both hands	Scientist wipes right hand	1	1
				Scientist wipes right hand	2	2
	2	2	Self-wipe both hands	Scientist wipes left hand	1	3
				Scientist wipes left hand	2	4
Part 2	3	3	Self-wipe both hands		3	5
	4	4	Self-wipe both hands		4	6

the casting, pasting, and assembly areas of the manufacturing site.

After a short demonstration, 18 of the volunteers were supervised by a scientist while self-wiping their hands following Protocol A. All but one self-wiped their hands without supervision on a further two additional occasions in their shifts, the other self-wiped on only one occasion. Five employees among the 23 volunteers were taught how to self-wipe their hands by local supervisors who had access to the protocol details but who had not been formally trained. These five employees did not follow the wiping protocol accurately. These results were excluded from the study.

Comparing Protocols A and B

The differences and similarities between protocols A and B are highlighted in Table I. The differences occur in part 1 of the wiping procedures. The least efficient part 1 will leave correspondingly more to be recovered in part 2. The common procedure of part 2 will recover at least some of what is left on the hands after part 1. Any difference in the relative recovery efficiency of the two protocols will be attributed to the differences between the first parts (i.e., part (1) of the procedures.

RESULTS AND DISCUSSION

Comparison of Two Hand Sampling Protocols

Table II presents a summary of the lead loadings collected from the hands of eight employees of a double glazing panel manufacturer. Hand wipes were collected before the start of the shift and either before or after the morning and lunch breaks. Five employees were sampled following Protocol A and three employees were sampled following Protocol B. The total amount of lead removed from employees' hands is presented in Table II. This is the sum of the four wipes used in Protocol A and the sum of the six wipes used in Protocol B.

Lead was present on all employees' hands before the work started at levels ranging from 11–313 μg with geometric mean of 122 μg . The total amount of lead accumulated on employees' hands during the work period investigated ranged from 248–4544 μg with geometric mean of 1378 μg .

Table III compares the efficiency of the wiping protocols based on the mean relative lead levels recovered using successive wipes at different periods of the work shift. The results are calculated for each protocol as arithmetic means with associated standard deviations (Stdev). In Table III, the results of the first and third wipes collected following Protocol B are

TABLE II. Summary of Lead Loadings on Hands of Employees of a Double Glazing Panel Manufacturer

Employee ID (Protocol used)	Before Start of Shift	Morning Break		Lunch Break		Full Period Total Pb (μg)
	Before Work Pb (μg)	Before Break Pb (μg)	After Break Pb (μg)	Before Break Pb (μg)	After Break Pb (μg)	
Pan1 (A)	313	1931			814	3058
Pan2 (A)	184		783	2745		3712
Pan3 (A)	42	163			43	248
Pan4 (A)	286		167	442		896
Pan5 (A)	11		219	487		717
Pan6 (B)	140	1124			276	1540
Pan7 (B)	163	596			270	1030
Pan8 (B)	282		812	3450		4544

TABLE III. Mean Relative Lead Recovery for Protocols A and B

	Pass number	Hand (wipe number)	Protocol A Pb (%) AM	Protocol A Stdev (%)	Hand (wipe number)	Protocol B Pb (%) AM	Protocol B Stdev (%)	T-test <i>p-value</i>
Part 1	1	Both (1)	51	8	Right (1) + Left (3)	48	5	0.23
	2	Both (2)	22	3	Right (2) + Left (4)	18	4	0.006
Part 2	3	Both (3)	15	4	Both (5)	20	4	0.008
	4	Both (4)	13	5	Both (6)	15	3	0.25
Total			100 n = 15		Total	100 n = 9		

Notes: AM, arithmetic mean; Stdev, standard deviation; n, number of hand wipes sets collected at a double glazing panel manufacturer using each protocol; T-test, two-tailed Student's t-test on mean relative recoveries of protocols A and B, significance level set at 0.05; *p-value*, output of two-tailed Student's t-test

combined for direct comparison with Protocol A. Similarly, the results of the second and fourth wipes collected following Protocol B are also combined for direct comparison with Protocol A.

Figure 4a presents the same data using a bar chart. The numbers on the horizontal axis identify the wipes (i.e., wipe number) that have been collected. Wipes collected separately from the right and left hands following Protocol B are com-

bined. The lead levels recovered on the fourth pass remain significant at more than 10% of the total recovered loadings.

Two-tailed Student's t-tests are used to evaluate the statistical significance of the differences observed in Figure 4a. The *p-values* obtained (reported in Table III) demonstrates that the differences in the means of the recoveries for passes 1 and 4 are not statistically significant (*p-value* > 0.05) while the differences observed for passes 2 and 4 are (*p-value* < 0.05). Unfortunately, this initial analysis is indecisive at determining whether Protocol A or B is more efficient at recovering lead dust from the hands of employees.

For this reason, further statistical analysis is required. The mean relative lead recoveries of the wipes collected in part 1 of the protocols are combined and presented in Figure 4b together with the combined results of the wipes collected in part 2. The mean relative lead recovery in Part 1 of Protocol A account for about 73%. For Protocol B, it only accounts for about 65%. The significance of the difference observed is investigated using a two-tailed Student's t-test. A *p-value* of 0.02 is obtained confirming that the observed difference is statistically significant and demonstrating that part 1 of Protocol A is slightly more efficient than part 1 of Protocol B.

Cumulative Step-by-Step Comparison Method

Table IV presents the relative lead recoveries from composite consecutive passes for protocols A and B. Repeat wipes are required to ensure that a sufficient proportion of the removable residue is recovered to allow a reasonable assessment of workplace exposure. This can be done by evaluating each successive step of the procedures.

The results of the first passes against the combined results of the first two passes are discussed. For Protocol A, this is about 70%, hence smaller than 75%, suggesting that using one pass following Protocol A is not an efficient sampling method based on ASTM method E1792-96a criterion.⁽¹⁴⁾ For Protocol B, it is slightly greater at approximately 73% but still smaller than 75%. Boeniger⁽⁹⁾ reported relative recoveries ranging from 82–87% for Ghost wipes. This apparent discrepancy might be due to differences in the type and levels of dusts encountered in the workplace and simulated in the laboratory. However, it

TABLE IV. Wipes Recovery Efficiency for Protocols A and B used at Double Glazing Panel Manufacturer

	Protocol A AM $\pm$ Stdev (%)	Protocol B AM $\pm$ Stdev (%)	T-test <i>p</i> -value
First pass vs. first two passes	69.8 $\pm$ 4.7	72.8 $\pm$ 4.6	0.14
First two passes vs. first three passes	83.3 $\pm$ 4.9	76.5 $\pm$ 5.6	0.005
First three passes vs. first four passes	87.5 $\pm$ 4.9	85.3 $\pm$ 3.3	0.25

Notes: AM, arithmetic mean; Stdev, standard deviation; T-test, two-tailed Student's t-test on successive cumulative recoveries of protocols A and B, with significance level set at 0.05; *p*-value, output of two-tailed Student's t-test

might also be due to the use of different skin wiping protocols. A Student's t-test performed on the relative recovery from the first passes against the first two passes indicates that there is no statistical difference between protocols A and B (*p*-value of 0.14 reported in Table IV). However, a single hand wipe collected following either protocol will not provide a good enough measure of the actual lead residues accumulated.

Comparing the cumulative results of the first two passes to the first three passes reveals a relative recovery of approximately 83% for Protocol A and 77% for Protocol B. The first two passes constitute part 1 of the wiping protocols. The third pass constitutes the first half of part 2 of the protocols. These results would suggest that self-wiping is slightly more efficient although there is not a clear distinction between the protocols when the standard deviations of the individual results are taken into consideration. However, a two-tailed Student's t-test provides a *p*-value of 0.005 (reported in Table IV), confirming that part 1 of Protocol A is more efficient than part 1 of Protocol B. The cumulative results suggest employees' hands should be wiped at least twice.

Finally, the results of the first three passes against the combined results of the first four passes are discussed. They account for approximately 87% for Protocol A and 85% for Protocol B. This small observed difference is not found to be

statistically significant (*p*-value of 0.25 in Table IV). More generally, there is not a clear decrease in the amount of lead recovered with repeat wipes. This might be explained by the sudden or chaotic release of dust residues more strongly attached to the skin or trapped under the finger nails of the employees. It might be necessary to wipe the hands of employees up to four times. Boeniger⁽⁹⁾ suggests that even after combining four consecutive Ghost wipes the total recovery does not exceed 71% of the applied dose.

In summary, based on an observation of the means and standard deviations of the relative recoveries of consecutive passes and two-tailed Student's t-tests performed (see Table III), it is not possible to indicate that one protocol is more efficient than the other at intermediate stages (i.e., when each pass is considered separately). However, further two-tailed Student's t-tests performed on the combined mean relative lead levels recovered in part 1 of the protocols (i.e., first two passes are combined) and on the cumulative results of the first two to the first three passes of the protocols (see Table IV) confirmed that part 1 of Protocol A is more efficient than part 1 of Protocol B. In addition, Protocol A is the simplest protocol to deploy and therefore, the one to use for sampling hands in the workplace. Protocol A was further tested at a lead battery manufacturer, a site where extreme levels of hand contamination were expected.

TABLE V. Summary of Lead Loadings Retrieved from Employees' Hands at a Lead Battery Manufacturing Site

Employee ID	Total Pb Pb (μ g)	Employee ID	Total Pb (μ g)
Bat1	10157	Bat10	14718
Bat2	12423	Bat11	1045
Bat3	8627	Bat12	5798
Bat4	18784	Bat13	4299
Bat5	2511	Bat14	3157
Bat6	3266	Bat15	9562
Bat7	3929	Bat16	5431
Bat8	2573	Bat17	149
Bat9	2204	Bat18	133 ^A

^Aindicates that employee's hands were sampled only once during the shift (all other employees sampled on three occasions).

FIGURE 5. Total lead residues collected from employees hands at two manufacturing sites (B above symbol indicates protocol B rather than A was used).

TABLE VI. Relative Lead Levels Recovered by Employees at Two Manufacturing Sites using Sampling Protocol A

Hand (wipe number)	Glass factory		Battery factory	
	Mean Pb (%)	Stdev (%)	Mean Pb (%)	Stdev (%)
Both (1)	51	8	50	10
Both (2)	22	3	23	4
Both (3)	15	4	15	4
Both (4)	13	5	12	6
Total	100 n = 15		100 n = 52	

Notes: AM, arithmetic mean; Stdev, standard deviation; n, number of hand wipes sets collected.

Results of Hand Sampling Protocol A at a Lead Battery Manufacturing Site

The total amounts of lead accumulated on the hands of 18 employees at a lead battery manufacturing site are presented in Table V. All employees followed Protocol A. The results ranged from 149–18,784 μg of lead with geometric mean of 4170 μg . These represent the sum of all the wipes collected during the shift of each employee. However, the results from one employee are not reported here because only one sample was collected. Results for individual wipes or wipes collected at a particular time during a shift are not presented.

Figure 5 presents the range of total lead levels collected by employees at the two manufacturing sites using Protocol A (for completeness, three results from the glass panel site obtained using Protocol B are also presented). None of the results from the glass panel manufacturing site exceed 5mg while about half the results from the battery manufacturing site exceed it. Nearly 20 mg of lead has been retrieved by self-wiping by one employee working in the lead battery manufacturing site.

Table VI shows the mean relative levels of lead recovered by employees at the two manufacturing sites exclusively self-wiping their hands using Protocol A. The relative mean lead levels are similar suggesting that the recovery efficiency of the hand sampling protocol is not affected by either the origin of the residues accumulating on the employees' hands or the levels of contamination. However, the standard deviations at the battery site are slightly greater than at the double glazing panel manufacturer site. One factor which might explain this is that employees at the lead battery site were only supervised during only one of three sampling periods during their shift. Unsupervised employees might have been less focused or careful while self-wiping their hands. Individual wipe results suggest that some employees are likely to have placed successive wipes randomly in the numbered sample tubes provided rather than bottling each wipe in the tube corresponding to the order the wipe was taken. Although this has no consequence for the estimation of the total skin loadings, it helps to identify individuals that might be less willing to do the task meticulously.

CONCLUSIONS

Protocol A was selected as the most practical and efficient protocol as it only requires employees to wipe their own hands using up to four wipes (vs. up to six wipes for Protocol B) and achieved more than 75% successive relative recovery after only two wipes (vs. four wipes for Protocol B).

This self-sampling protocol can be used by occupational hygienists or other competent persons to sample relatively large groups of employees in a relatively short time. Although this project focused on the evaluation of skin contamination by lead dust residues in the workplace, the hand wiping protocol designed here can be applied to other non-soluble compounds (i.e., other heavy metals or substances) that might be of concern.

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