Skin Absorption of Inorganic Lead (PbO) and the Effect of Skin Cleansers

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Objective: *The aim of this study was to investigate the percutaneous penetration of lead oxide (PbO) powder and the effect of rapid skin decontamination with two different detergents.* ***Methods:*** *Franz cells were used to study in vitro PbO skin penetration through human skin during a 24-hour period. The tests were performed without or with decontamination using either Ivory Liquid soap or a new experimental cleanser 30 minutes after the start of exposure.* ***Results:*** *We confirm that PbO can pass through the skin with a median penetration of 2.9 ng/cm^2 (25–75th percentiles 0.35–6). The cleaning procedure using Ivory Liquid soap significantly increased skin penetration with a median value of 23.6 ng/cm^2 (25–75th percentiles 12–47.1; Mann-Whitney* U *test,* P = *0.0002), whereas the new experimental cleanser only marginally increased penetration (7.1 ng/cm^2).* ***Conclusions:*** *Our results indicate that it is necessary to prevent skin contamination from occurring because a short contact can increase skin content and penetration even if quickly followed by washing. This study demonstrated that PbO powder can pass through the skin and that skin decontamination done after 30 minutes of exposure did not decrease skin absorption occurring over 24 hours and stresses the need to prevent skin contamination when using toxic substances.* (J Occup Environ Med. *2006;48:692–699*)

Skin contamination by dusts containing lead and other toxic metals is not generally regarded by many as posing a significant risk from percutaneous penetration and any toxic effect that is due to systemic uptake. Limited experimental studies suggest that under physiologically relevant conditions, metal dusts may ionize, which can result in percutaneous absorption of toxic metals.[1–3] It is known that polar organic compounds and some metals can appreciably penetrate damaged skin, but this has not been studied in regard to lead particulate compounds (eg, PbO, PbO_2, and so on); previous in vivo experiments with inorganic lead compounds indicate penetration through the skin,[1] but there was previously no information on the effect on penetration of decontamination agents.

In industrial settings, skin contamination is fairly common, and the cleaning procedure may visibly remove most of the toxic agent. However, washing may also increase skin uptake by the penetration-enhancing effect of the surfactants. For example, sodium lauryl sulfate can increase the skin penetration of some toxic substances[4,5] because it has a disruptive action on stratum corneum by changing its lipid composition,[6] extracting lipids from the intercellular spaces in the stratum corneum,[7,8] and changing alpha-keratin into beta-keratin that causes swelling and hydration of the stratum corneum.[9,10]

On the other hand, creams and detergents containing chelating agents have been suggested for use in nickel-sensitized people to prevent nickel der-

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matitis,[11,12] and such a skin cleanser might also be used in industrial settings to prevent absorption of other metal ions. For this reason, researchers at the National Institute for Occupational Safety and Health (NIOSH) formulated a cleanser based on acidification, surfaction, and chelation that might reduce skin absorption of metal ions.

The aim of our study was to investigate the skin absorption of PbO, the effect of skin decontamination with two different cleansers, one containing sodium lauryl sulfate (Ivory Liquid Soap) and another containing a new novel formulation (NIOSH cleanser). Experiments were run using normal skin as well as abraded skin following the Bronaugh protocol[13] to better understand the effect of skin lesions on skin absorption.

Materials and Methods

In vitro skin permeation using human skin was measured using the Franz method.[14] A piece of full-thickness human abdominal skin, obtained as surgical waste from a hospital, was excised, cut in pieces, immediately placed in plastic bags (2–4 skin pieces in each bag), and stored in a freezer (−25°C) for a period up to, but not exceeding, 4 months. Before use, the skin was left to thaw gradually to room temperature followed by removal of all subcutaneous fat with a scalpel. From each specimen, multiple 4 × 4-cm^2 pieces were cut and mounted separately in eight static Franz diffusion cells consisting of an exposure and receiving chamber. For each experiment type, skin was obtained from two or more skin donors. In total, skin from 14 donors was obtained, yielding two to 12 skin pieces per donor. On the day of the experiment, three to four plastic bags (each containing skin from at least two donors) were randomly selected and the skin pieces were mounted in each diffusion cell (including blank [no treatment] and treatment cells). The epidermal side of the skin (thickness approximately 1 mm) was exposed to room conditions, whereas the dermal side was bathed in a physiological solution.[15] Temperature was maintained at approximately 32°C (temperature of human in vivo skin) by circulating water through a jacket surrounding the chamber. Skin integrity was tested using electrical resistance.[16]

All chemicals were of analytical grade. NaCl was obtained from BDH Laboratories Supplies (Poole, U.K.); lactic acid, urea, and pure hydrochloric acid (34%) were purchased from Carlo Erba (Milan, Italy); ammonium hydroxide (25%) was purchased from J. T. Baker (Deventer, Holland). PbO powder was supplied by NIOSH with particles of diameter <10 μm. The physiological solution used as the receiving fluid was prepared by dissolving 2.38 g of Na_2HPO_4, 0.19 g of KH_2PO_4,and 9 g of NaCl into 1 L of milliQ water (final pH = 7.35). Synthetic sweat was prepared with deionized and aerated water at room temperature (20°C). It contained sodium chloride (0.5%), lactic acid (0.1%), and urea (0.1%) and the pH was adjusted up to 5.0 with ammonia (500 mL of synthetic sweat contained 2.5 g NaCl, 0.5 g urea, 0.5 g lactic acid). The solution was used within 3 hours of preparation.[17] The skin cleansers selected included the following:

Cleanser 1: Ivory liquid soap containing sodium lauryl sulfate and sodium laureth sulfate (Procter & Gamble, Cincinnati, OH); and
Cleanser 2: NIOSH cleanser containing a proprietary formulation (patent pending).

Each glass static cell had an available skin surface area for diffusion of approximately 3.14 cm^2 and a cell volume of approximately 14 mL.

The experiments were performed as follows.

Experiment 1

The skin pieces were cut and mounted in the Franz cells. Each cell was filled with 5 mg PbO per square centimeter and with 2 mL synthetic sweat at pH 5.0. At 24 hours, the receiving solutions were removed and Pb concentrations were determined. At the same time the skin samples were removed from the test chamber, the surface was cleaned with running water for 30 seconds and then wiped with three dry cotton balls to remove surface contamination. The skin samples were analyzed for Pb content as described subsequently in the analytical measurement section.

Experiment 2

The skin pieces were cut larger than 4 cm × 4 cm to make handling easier during the cleaning procedure and to avoid contamination of the underside of the skin. Like in experiment 1, at time 0, the exposure chambers of eight Franz diffusion cells were each filled with 5 mg PbO per square centimeter and 2 mL synthetic sweat at pH 5.0. However, after 30 minutes, the donor solution was removed using a syringe and three cotton balls. The skin pieces were next carefully removed from the Franz cells, cleaned with one cotton ball wetted with cleanser 1, then rinsed under running water for 30 seconds followed by gently wiping for 10 seconds each with three dry cotton balls. After the cleaning procedure, the skin pieces were remounted again on Franz cells and exposure chambers were filled with 2 mL synthetic sweat at pH 5.0. At 24 hours, the receiving phase was removed and Pb concentration was determined in each individual receiving chamber solution and in the skin tissue pieces.

Experiment 3

The experiment was performed like experiment 2 using cleanser 2 (NIOSH cleanser).

Experiments 4, 5, and 6

Experiments 1, 2, and 3 were repeated using an abraded skin protocol[13]; skin was abraded by drawing the point of a 19-gauge hypodermic needle across the surface (20 marks in one direction and 20 perpendicular).

Blanks. For each experiment, four cells were added as blanks (total 24 cells). The blank cells were treated as the other cells with the exception that no Pb powder was introduced to the exposure chamber. In experiments 2, 3, 5, and 6 involving treatment with two skin cleansers, to avoid cross-contamination, skin pieces were removed from the blank test cells and rinsed before conducting the cleanser treatment in the experimental cells. The median blank value from each experiment group, which included the reagent blank value, was subtracted from the results obtained from each lead-fortified experimental test.

Analytic Measurements

The receiving fluid measurements were performed by electrothermal atomic absorption spectrometry (ETAAS) with Zeeman background correction according to NIOSH method no. 7105 (lead by ETAAS).[18] The instrument used for analysis was a Perkin Elmer 4100ZL spectrophotometer equipped with an HGA graphite furnace and autosampler AS/71. The analytical wavelength was of 283.3 nm and slit width of 0.7 nm.

Reagents were of analytical grade: HNO_3 70% (J. T. Baker Ultrex II), HCl 37% (J. T. Baker Ultrex II), $Mg(NO_3)_2$ (Merck), $(NH_4)H_2PO_4$ (Merck). The nitric and hydrochloric acids were used for decontamination of glass and plastic devices. Nitric acid (0.3%) was also used to acidify Pb standard stock solutions. $Mg(NO_3)_2$ and $(NH_4)H_2PO_4$ were used as matrix modifiers in atomic absorption analysis.

We used Pb standard solution (1000 μg/mL) (J. T. Baker refers to NIST standard).

The limit of detection (LOD) for Pb is 0.2 μg/L with an injection of 20 μL of sample for analysis; every sample was added up with 0.1% solution of $Mg(NO_3)_2$ and 1% $(NH_4)H_2PO_4$ as matrix modifier.

Quality Control Samples: the Standard Reference Materials NIST SRM 1640 and 1643 days were analyzed with the sequence of all samples as a quality control check to validate the analytical method (guarantee data quality). The laboratory participates in an external quality control for lead in blood with Italian "Istituto Superiore di Sanità" (Progetto METOS). Blanks of the materials in use and reagent blanks were analyzed to detect interference and contamination. The analytical data were subtracted from the values determined for the samples.

Evaluation of the Skin Pb Content

After the experiments, the skin was cut into sections and put into a beaker with 5 mL HNO_3 70%. It was then agitated for 12 hours and centrifuged for 5 minutes at 1000 rpm. The supernatant was removed and analyzed by ETAAS as described previously.

Data Analysis

The lead concentration (ng/mL or ng/cm^3) of each receiving solution was converted to the total amount penetrated expressed for exposed skin surface area (ng/cm^2) with a correction for the total receiving cell volume. In each experimental treatment, the median value of the blank cells was subtracted from the median value of the lead-fortified cells.

Data analysis was performed using Excel for Windows software (Microsoft) and SPSS Statistics Software. Data are reported using the box-plot technique that presents the data distribution as the median, 25–75th percentiles, and lower and upper range. All data were tested for normal distribution (Kolmogorov-Smirnov) and for homogeneity of variance (Levene-F test). The nonparametric statistical tests (Kruskal-Wallis H-test and Mann-Whitney *U* test) were then applied. A P value of <0.05 was considered significant.

To estimate the potential impact of dermal absorption on blood lead, the dermal uptake results were used together with the USEPA Adult Lead Model (http://www.epa.gov/superfund/programs/lead/products.htm). The Adult Lead Model projects an increase in the steady-state blood level of 0.4 μg/dL for each microgram of lead absorbed per day. Additional assumptions made were that a worker would be chronically exposed to a dermal load of 5 mg PbO/cm^2 for 250 days/year and that the surface area exposed was equivalent to the hands (840 cm^2), hands + arms (3120 cm^2), or hands, arms, head, and neck (4520 cm^2).[19,20]

Results

Table 1 reports the Pb concentration in the receiving cells as median, 25–75th percentiles, minimum, and maximum (ng/cm^2).

In the blank cells, we found a low Pb concentration related to the normal Pb content in skin, lower in experiments done without the use of a cleansers (exp 1 and 4) and higher in experiments performed using Ivory soap, probably related to the low amount of Pb found in this cleanser (672 μg/L).

Figure 1 shows the box plot analysis for experimental cells. The values were obtained by subtracting the median value of the blank cells for each experiment from the treatment results of each experiment. The lines in the box plots represent the median values, the 25th and 75th percentiles, and range. In the statistical analysis, the extreme values were included.

In experiments 1 and 3, we obtained the lowest values of Pb in the receiving solutions, respectively, 2.9 and 7.1 ng/cm^2 ($P = 0.03$). Ivory soap (exp 2) increased penetration by eightfold (Mann-Whitney *U* test between exp 2 and 1 $P = 0.001$) with a median value of penetration in 24 hours of 23.6 ng/cm^2. The difference in penetration between Ivory soap (exp 2) and the NIOSH cleanser (exp 3) was also statistically significant ($P = 0.01$).

Penetration of lead through damaged skin (exp 4) was nine times greater (26.8 ng/cm^2) than through intact skin when no cleansers were used (exp 1). When the NIOSH cleanser was tested on damaged skin, penetration of lead increased (35.9 ng/cm^2) but was not significant

TABLE 1
Summary Statistics Pb Content in the Receiving Cells: Median and 25–75th Percentiles (ng/cm^2)

	Median	25th Percentile	75th Percentile	Minimum	Maximum
Experiment 1					
Blank cells	2.5	1.9	4.3	1.7	4.9
Experimental cells	5.4	2.8	8.5	2.7	13.4
Blank-adjusted	2.9	0.35	6.0	0.2	10.9
Experiment 2					
Blank cells	15.0	14.8	15.4	14.8	15.5
Experimental cells	38.6	27.0	62.1	19.3	103.0
Blank-adjusted	23.6*†	12	47.1	4.3	88.0
Experiment 3					
Blank cells	1.7	1.3	5.7	1.2	7.2
Experimental cells	8.8	7.5	11.7	4.5	15.5
Blank-adjusted	7.1*	5.8	10.0	2.8	13.8
Experiment 4					
Blank cells	2.1	0.9	3.9	0.9	4.2
Experimental cells	28.9	17.8	38.5	8.6	146.0
Blank-adjusted	26.8*	15.7	36.4	6.5	143.9
Experiment 5					
Blank cells	9.9	5.0	13.5	3.4	14.6
Experimental cells	110.1	93.1	142.6	41.7	149.2
Blank-adjusted	100.2*†	83.2	132.7	31.8	139.3
Experiment 6					
Blank cells	4.6	1.2	9.9	0.4	11.4
Experimental cells	40.5	34.6	50.0	23.6	52.6
Blank-adjusted	35.9*	30.0	45.4	19.0	48.0

*Mann-Whitney test $P < 0.05$ between blank and experimental cells.
†Mann-Whitney test $P < 0.05$ between exp 1 and 2, exp 2 and 3, exp 5 and 4, exp 5 and 6.
exp 1: PbO powder exposure for 24 hr.
exp 2: PbO powder exposure for 30 min and wash with Ivory soap.
exp 3: PbO powder exposure for 30 min and wash with NIOSH cleanser.
exp 4: PbO powder exposure for 24 hr on damaged skin.
exp 5: PbO powder exposure for 30 min and wash with Ivory soap on damaged skin.
exp 6: PbO powder exposure for 30 min and wash with NIOSH cleanser on damaged skin.

(Mann-Whitney U test $P = 0.13$), whereas when using Ivory soap, the penetration increased significantly to 100.2 ng/cm^2 ($P = 0.01$).

When Ivory soap was used on damaged skin, the receiving solution contained four times more lead than the skins that had not been treated with a cleanser (Mann-Whitney U test $P < 0.01$) and 2.8 times more lead than those skins that had been treated with the NIOSH cleanser (Mann-Whitney U test $P < 0.01$).

Skin Pb Content

The Pb skin content is reported in Table 2. The Pb skin content was higher in experiments done without the washing procedure (exp 1 and 4) and was lower when the skin was exposed and then washed with cleanser and water.

Figure 2 shows the box plots of Pb found in or on the skin. When no skin cleanser was used, the content of lead remaining in the skin after removing the skin from the test cells was similar in intact and damaged skin (321 vs 297 ng/cm^2). In the test cells in which the NIOSH cleanser was used (exp 3 and 6), there was a 30-fold reduction in the intact skin set and a 16-fold reduction in the damaged skin set in the amount of lead found present in the skin (Mann-Whitney U test $P < 0.001$). When the Ivory liquid cleanser was used (exp 2 and 5), there was a 16-fold reduction ($P = 0.001$) in intact skin and a twofold reduction (Mann-Whitney U test $P = 0.105$) in damaged skin. The difference in the amount of lead remaining in the skin between the NIOSH cleanser and Ivory cleanser in intact skin was not statistically significant (Mann-Whitney U test $P = 0.195$), but it was statistically significant for damaged skin (Mann-Whitney U test $P = 0.005$).

The potential impact of occupational dermal exposure to lead on blood lead was estimated based on the dermal lead uptake data from Table 1. Assuming that either the hands, hands, and arms or hands, arms, head, and neck would be exposed to 5 mg PbO/cm^2, for 250 days/year, the steady-state increase in blood lead for unwashed skin is projected to be 0.7 (0.1,1.4), 2.5 (0.3, 5.1), or 3.6 (0.4, 7.4) μg/dL, respectively, in which the numbers in parentheses represent the interquartile range. Under the same assumptions, the increased blood lead due to uptake through skin washed with sodium lauryl sulfate is estimated to be 5.4 (2.8, 10.8), 20.2 (10.3, 40.3), or 29.2 (14.9, 58.3) μg/dL, respectively, for chronic occupational exposures to either the hands, hands, and arms or hands, arms, head, and neck.

Discussion

It has been reported previously that inorganic lead can pass through the skin. Lilley et al[21] and Florence[22] demonstrated that solubilized Pb nitrate can pass through the skin and then be secreted from the sweat. They also applied metallic Pb and PbO on the skin, and there was lesser evidence of elevated amounts of Pb in the sweat at distant sites for 2 days. Neither of these authors found an increase of Pb in the blood, speculating that this was perhaps due to some unique process in which dermally absorbed lead is present primarily in the plasma and extracellular fluid. A weakness of these publications was that the experiment with lead powder was performed on

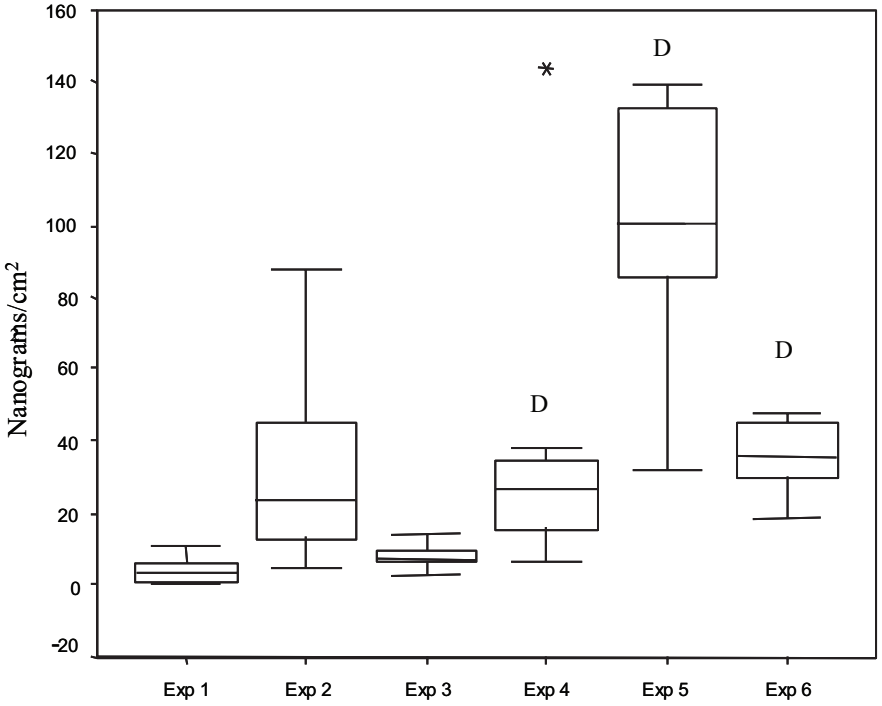

Fig. 1. Skin penetration of Pb at 24 hours: the blank-adjusted value of the experimental cells was obtained by subtracting the median value of the blank cells included in that experiment (*outlier). Exp 1, 2, and 3 is intact skin; exp 4, 5, and 6 is damaged skin (D).

TABLE 2
Summary Statistics for Pb Content in the Skin (ng/cm^2)

	Median	25th Percentile	75th Percentile	Minimum	Maximum
Experiment 1					
Blank cells	0.1	0.1	0.1	0.1	0.1
Experimental cells	321.4	243.4	528.4	191.5	833.3
Blank-adjusted	321.3*†	243.3	528.3	191.4	833.2
Experiment 2					
Blank cells	0.9	0.7	1.2	0.8	1.3
Experimental cells	20.6	12.2	35.5	5.6	148.6
Blank-adjusted	19.7*	11.3	34.6	4.7	147.7
Experiment 3					
Blank cells	0.2	0.1	0.5	0.1	0.6
Experimental cells	10.7	6.4	19.5	4.7	42.04
Blank-adjusted	10.5*	6.2	19.3	4.5	41.8
Experiment 4					
Blank cells	0.2	0.1	0.3	0.1	0.3
Experimental cells	297.1	165.3	716.9	46.5	1,933.5
Blank-adjusted	296.9*†	165.1	716.7	46.3	1,933.3
Experiment 5					
Blank cells	0.5	0.4	1.8	0.4	2.2
Experimental cells	140.1	77.5	224.9	66.5	348.5
Blank-adjusted	135.6*	77.0	224.3	66.0	348.0
Experiment 6					
Blank cells	0.2	0.1	0.2	0.1	0.2
Experimental cells	19.9	7.5	69.9	5.4	118.5
Blank-adjusted	19.7*	7.3	69.7	5.2	118.3

*Mann-Whitney U test $P < 0.05$ between blank and experimental cells.
†Mann-Whitney U test $P = 0.001$ between exp 1 and 2, 1 and 3, 4 and 6, $P = 0.02$ between exp 2 and exp 5.

only one individual and for PbO no actual data were reported.

Stauber[1] in 1994, using radiolabeled Pb acetate or Pb nitrate, provided evidence of skin absorption of this form of soluble lead in volunteer people, with increased lead in sweat, in blood, and in urine for 16 days. More recently, Sun et al[23] reported new data on skin penetration of lead metal powder in exposed workers and in rats. They found that Pb concentration in the stratum corneum from the hands to be correlated to Pb content in workers' blood and in urine. In rats, lead metal powder, or PbO, was applied to the skin under wrap for 12 days and both resulted in significant elevations of Pb in urine. Until the present study, there has never to our knowledge been an in vitro study of skin penetration by PbO through human skin, and none of the previous researchers studied the effect of decontamination cleansers on skin penetration.

Our study found that lead oxide can pass through intact human skin with a median amount at 24 hours of 2.9 ng/cm^2 (25–75th percentiles 0.35–6.0). This penetration increased ninefold when we used an abraded skin protocol as suggested by Bronaugh.[13] Significantly increased penetration of other metals through damaged skin has been reported.[24] The choice of pH 5 in our synthetic sweat was somewhat unusual in that many other in vitro studies choose a pH of 6.5 for their simulate sweat (EEC[25]). However, the actual pH of human skin appears to be much more acidic, typically in the range of 4 to 5.5 and in some cases much below this.[26,27] This is an extremely important characteristic, because most elements become appreciably more ionized as the acidity increases, ie, approximately 10- to 100-fold with each one pH unit decrease.[28] It is well known that elements will penetrate skin more readily when present in this ionized form. For example, metallic cobalt can pass through the skin only if in the ionized form of the metal.[15] Thus, the choice of a simulate sweat

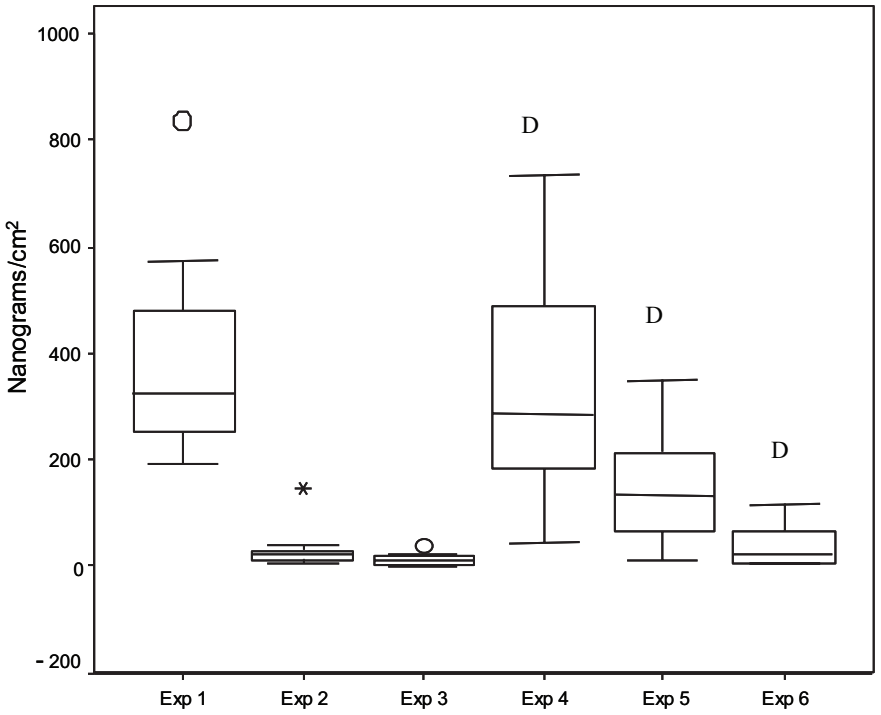

Fig. 2. Pb skin content: the blank-adjusted value of experimental cells was obtained by subtracting the median value of the blank cells (*, °outlier) exp 1, 2, and 3 intact skin. Exp 4, 5, and 6 damaged skin (D). In exp 4, the highest value is not shown.

pH of 5 as used in the present study was considered appropriate to simulate workplace conditions.

One aspect of this in vitro study, which may not be realistic is having the stratum corneum exposed to simulate sweat for 24 hours. In the lead-exposure trades, workers may work in hot environments for 8 or more hours. Their skin may become contaminated and then be covered by occlusive clothing. However, the skin is not expected to be covered by sweat for 24 hours. Excessive hydration is known to facilitate penetration of many organic compounds, but there is little research to demonstrate this effect on metallic ion penetration.[29] However, Fullerton et al demonstrated a multifold increase in the in vitro penetration of nickel chloride through human skin when occluded.[30] On the other hand, even when the skin was exposed for only 30 minutes to PbO and then decontaminated, lead had been found to penetrate completely through the full-thickness skin. This would suggest rapid initial uptake. Another aspect of our in vitro test method that may be different from in vivo workers' skin is that the skin in our study was static. Tinkle et al, on the other hand, found that 1-μm plastic beads, similar in size to the PbO powder used in our study, could penetrate human skin when flexed but not static.[31] How accurately these in vitro results relate to in vivo workers' skin is not known, but the results from this study and previous studies all indicate that lead can penetrate human and animal skin under the conditions used in the experimental protocols.

Choice of skin loading concentration can have a substantial impact on penetration rates and typically is proportional to penetration up to a point at which saturation of the penetrated skin membrane occurs. For a fine (1-μm) particle with the density of PbO (9.53), the estimated monolayer loading would be approximately 50 mg/cm^2.[32] In the present study, a loading level of 5 mg/cm^2 was chosen. However, this loading is much higher than most loading concentrations found in workplaces as reported in the literature.[33–39] Lower skin loadings, and perhaps a higher loading than used here, would be necessary to determine at which point of loading penetration rate deviates from a linear steady state.

Results from the experiments performed with two cleansers were noteworthy. First of all, removing Pb after 30 minutes did not cause a reduction of Pb penetration in 24 hours but only caused a reduction in skin Pb content. This suggests that removing Pb powder after 30 minutes is not sufficient to reduce the apparently rapid initial absorption that can occur during the first few minutes. In 30 minutes, perhaps a sufficient amount of Pb has already passed into the stratum corneum and created a concentration gradient or the decontamination with the cleansers was not complete and allowed penetration to continue. Such rapid Pb skin absorption is in accordance with previous reports.[23] It has also been previously reported that sodium lauryl sulfate can increase nickel penetration[4,5,40] by reducing the barrier integrity of the skin.[6] In our study, the washing procedure was also shown to significantly increase skin penetration when using a common cleanser containing sodium lauryl sulfate. Our results might similarly be explained as due to the disruptive effect of surfactants on the stratum corneum.[4,40]

The evaluation of the Pb skin content shows that the Pb concentration is more than 100 times higher in intact skin where PbO powder was applied for 24 hours, and not washed with a cleanser, than in skin washed with Ivory Liquid or the NIOSH cleanser (321.3 vs 19.7 and 10.5, respectively). The lead contents of unwashed intact or damaged skin were similar (321.3 vs 291.9), but in the skin-washed experiments, the difference was significantly greater between intact versus damaged skin washed with Ivory Liquid Soap (19.7 vs 135.6, $P = 0.02$), but not significantly different when the NIOSH cleanser was used (10.5 vs 19.7, $P = 0.0\ 2$). The washing procedure with

both cleansers can significantly decrease the Pb skin content, but in the abraded skin, the reduction in skin content was less pronounced.

Using the in vitro lead uptake data from this study to estimate chronic blood lead concentrations in vivo suggests that given the assumptions used, the contribution of dermal lead uptake to blood lead could be substantial. Our results suggest a possible increase in blood lead concentration of up to 7.4 μg/dL for exposures that are allowed to remain on the skin for a prolonged period and up to 58.3 μg/dL if the barrier properties of the stratum corneum are damaged by sodium lauryl sulfate. However, certain assumptions and conditions used in this in vitro protocol merit comment, and these estimates may not realistically represent actual workplace conditions. Several factors and assumptions inherent to our protocol that might contribute to an upward bias in percutaneous penetration, as discussed previously, might include a prolonged hydration of the stratum corneum with sweat and the lead loading amount applied. On the other hand, workers are likely to wash more than once per day and often have mechanically damaged skin that includes cuts and abrasions, which the evidence suggests would make penetration substantially worse. Our risk analysis did not include these latter factors that would therefore lead to an underestimate of risk. Like with any in vitro study and human health risk modeling, extrapolating to "real-world" events is an imperfect art.

When the sum of the skin content and penetrated lead was used to compare the two cleansers, the difference was highly significant supporting the conclusion that the NIOSH cleanser did not significantly enhance penetration of lead into or through the skin when used and was more effective at removing lead from the skin, whereas the other common cleanser did increase penetration and skin lead content was higher.

These results indicate that it is necessary to prevent skin contamination by lead oxide from occurring, because a short contact, even if quickly followed by washing, can increase skin content and penetration. These results also suggest that it is necessary to carefully choose the decontamination measures that are provided to workers.

The limitation of this study is that in vitro studies, which can be helpful to understand skin absorption, is only a simple way to simulate what happens during real-life situations. Perhaps this study could be expanded to include dry challenge cell conditions and different challenge doses of PbO. It would be interesting to evaluate penetration using other skin cleansers to decontaminate the skin. New experiments would be useful to better understand Pb skin absorption and develop better prevention strategies. Finally, these laboratory findings should be confirmed with studies in workplaces that represent actual working conditions.

Conclusions

Our study provides new information on PbO skin penetration and the potential effectiveness of decontamination measures: 1) we demonstrated the in vitro skin permeation of PbO; 2) we confirmed the increase of penetration using damaged skin; 3) removing PbO powder after 30 minutes with the NIOSH cleanser does not reduce Pb penetration occurring over the subsequent 24 hours; 4) the use of a common cleanser can significantly increase Pb skin penetration in 24 hours; and 5) modeling of potential blood lead concentrations in adults due to chronic skin exposure to PbO suggests that uncontrolled skin exposure might substantially contribute to body burden.

Our study confirms the role of the skin as a permeable membrane and the need to prevent contact with xenobiotics. The cleaning procedure used to remove lead from skin must be chosen carefully.

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