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Evaluation of the Effectiveness of Hygenall© Leadoff™ Foaming Soap in Reducing Lead on Workers' Hands and the Uptake of Lead on Bridge Painting Projects

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Abstract

Although considerable research has been conducted regarding airborne lead exposures during lead paint removal, little data has been collected measuring the lead concentration on workers' hands in the construction industry. As a result, there are gaps in our understanding of the effectiveness of a standard work practice control (handwashing) in the prevention and control of elevated blood lead levels (BLLs) in the workplace. The primary objective of this study was to assess if a National Institute for Occupational Safety and Health (NIOSH) formulation intended to remove lead from skin (Hygenall© Leadoff™ Foaming Soap) is more effective than a commonly used soap in the industrial painting industry (Zep Cherry Bomb Soap) in reducing the concentration of lead on workers' hands after exposure. A secondary aim was to assess if using Leadoff™ Foaming Soap during handwashing reduces worker uptake of lead on bridge painting projects. We evaluated hand wipe, air sample and blood lead level data collected by two industrial bridge painting contractors. Airborne exposures ranged from 350 μg/m^3 to 19,700 μg/m^3. The geometric mean lead concentration remaining on workers' hands after using Zep Cherry Bomb Soap was 77 μg per hand wipe compared with 61 μg per hand wipe after use of Leadoff™ Foaming Soap for all work classifications. The geometric lead concentration on workers' hands decreased by 16 μg/hand wipe for all work classifications combined after using Leadoff™ Foaming Soap—a decrease of 21%. The use of Hygenall Leadoff™ Foaming Soap reduced the maximum lead concentration on workers' hands by 85%. The geometric mean BLL for all work classifications was 12.1 μg/dl before the use of Leadoff™. After two months of airborne exposure and use of Leadoff™ Foaming Soap at breaks and at the end of the workday, the geometric mean

BLL for all work classifications increased to 18.1 μg/dl. Worker BLLs increased despite the reduction in the concentration of lead measured on workers' hands—most likely a result of ineffective inhalation exposure controls. We found that the Leadoff™ Foaming Soap was more effective in removing lead from workers' hands than Zep Cherry Bomb.

Keywords

Dermal Exposure, Blood Lead Level, Bridge Painting, Handwashing

1. Introduction

In 1993 the Occupational Safety and Health Administration (OSHA) issued a lead construction industry standard to reduce workplace exposures to prevent BLLs > 25 μg/dl [1]. Despite many protective risk management provisions in the lead construction standard, and many years of focused intervention efforts through OSHA's National Emphasis Program [2] to reduce workplace lead exposure, elevated BLLs (>25 μg/dl) persist among workers in the industrial painting industry [3] [4].

While the intent of the lead standard is designed to reduce inhalation and ingestion exposure, OSHA's primary regulatory focus is on the inhalation pathway [5]. The construction lead standard requirements are driven by airborne exposure limits (Permissible Exposure Limit Level 50 $\mu g/m^3$ and Action Level 30 $\mu g/m^3$) to determine the acceptability of exposure and to prompt intervention efforts to reduce unacceptable exposures [5]. In contrast, OSHA's lead standard does not provide a dermal exposure limit that would trigger changes in project controls even though the ingestion route is a significant contributor to the uptake of lead [1].

Handwashing with soap and water is a standard work practice that is relied on by industrial bridge painters as an exposure control measure. Unfortunately, the OSHA construction lead standard is silent regarding the effectiveness of handwashing with soap and water as a means to remove lead from workers' skin. Research conducted by NIOSH identified a weakness in the lead standard's ingestion exposure control guidance when they observed that traditional handwashing with soap and water did not remove all lead from the workers' skin in various work settings [6] [7]. NIOSH's findings regarding the effectiveness of regular soap at removing lead from the skin are significant because residual lead on the skin increases the risk of lead uptake by hand-to-mouth ingestion [8].

To minimize lead ingestion exposure in the workplace, NIOSH developed a product that is more effective at removing lead from the skin than standard soap [9]. NIOSH reports their patented cleaning agent (textured wipe coated with isostearamidopropyl morpholine lactate (ISML) and citric acid) effectively removes lead from the skin (>99%) [10]. In 2008, NIOSH licensed its formulation to Hygenall Corporation [11]. Hygenall has used the NIOSH patent to develop and sell a product called Leadoff™ Foaming Soap (Leadoff).

The objective of this study was to assess if Leadoff soap is more effective than Zep Cherry Bomb soap (Cherry Bomb) in reducing the concentration of lead on workers' hands after exposure. A secondary aim was to assess if the use of Leadoff soap during handwashing reduces worker up-take of lead on bridge painting projects.

2. Methods

2.1. Study Population

We conducted a study of 44 industrial bridge painting workers from 2 bridge rehabilitation projects (1-Louisiana and 2-West Virginia) in the fall of 2019. Our study included an analysis of hand wipe, personal air sample, and BLL data collected by the participating contractors. Before beginning the data collection process, this study was submitted to the University of South Florida's Institutional Review Board. They reviewed it and determined it was exempt (IRB No. Pro00035891 and IRB No. Pro00036873).

We recruited industrial bridge painting contractors (Standard Industrial Classification-1721) for inclusion in this study from May 2019 to September 2019. We selected this population due to persistently elevated BLLs (>25 µg/dl) among such workers [3]. These workers were also chosen because OSHA estimated more painting contractor employees are exposed to lead than any other construction classification impacted by the regulation [1]. Also, OSHA recognized this group of workers as potentially exposed to the most intense lead exposure [1].

We developed inclusion criteria based on our previous research [4] to ensure comparable experience and technological aptitude among the contractors in implementing lead exposure controls. The inclusion criteria included:

- The contractor had to be certified by a third-party agency (SSPC) to conduct hazardous paint removal;
- The contractor had to have at least three years of experience in conducting hazardous paint removal while certified;
- The project specification required the implementation of lead exposure controls;
- The project specification required full containment (SSPC Class 1A) with mechanical ventilation as the engineering control;
- The owner of the bridge had a third-party firm on-site to ensure exposure control implementation and compliance with the project specification requirements;
- The project had environmental support such as decontamination trailers, handwashing facilities and lead warning signs;
- The contractor had a trained lead competent person on-site during any lead emission generating activities;
- All workers received lead training, hazard communication, and respiratory

protection training;

- Confirmation from the contractor of airborne lead exposures above the airborne PEL of 50 μg/m^3 at the worksite;
- Confirmation from the contractor that they used a CLIA accredited lab for the blood lead level analysis;
- Confirmation from the contractor that worker exposure to lead remained constant over the study period.

During the data collection phase of the study, there were 186 contractors certified by SSPC to remove hazardous paint. Out of the eligible painting contractors, 145 met the inclusion criteria. Two bridge painting contractors that met the study inclusion criteria agreed to participate in the study.

All of the study participants were men. The contractors provided no other demographic data. We created a data collection form to gather information on the work task during exposure, the matching BLL, and hand wipe results. The contractors that participated in the study removed all personal identifiers before the data was submitted. The contractors emailed their completed data collection forms to the authors. All data collected was considered by the contractors as regulatory compliance sampling. Thus, all workers were included in the study for BLL testing, and 34 out of 44 were selected for hand wipe sampling.

We identified two exposure groups (abrasive blaster/painter (ABP) & laborer) from 2 separate bridge painting projects. Based on conversations we had with the participating contractors, each worker was placed into an exposure group based on the similarity and frequency of the tasks they performed, the work process, and the controls in place. We considered the abrasive blasting and painting work tasks as one exposure profile like OSHA did in the construction lead standard.

Liquid Soap

The Cherry Bomb safety data sheet provided by the manufacturer lists the product form as a thick emulsion with a pH (concentrate) of 7.0 - 8.0. The exact formulation is not provided by the manufacturer. However, the product data sheet lists the following ingredients: distillates (petroleum) (≥20% - <30%), hydrotreated light (≥10 - <20), 4-Nonylphenol branched, ethoxylated (≥1% - <5%), 2-aminoethanol Tallate (≥1 - <5%), White mineral oil (petroleum) (≥1% - <5%), Solvent naphtha (petroleum), heavy aliph (≥1% - <5%) Poly(oxy-1,2-ethanediyl%), .alpha.-hydro-.omega (≥1% - <5%). The formulation for Leadoff is also a trade secret and is not provided by the manufacturer. The Leadoff safety data sheet lists the following ingredients: citric acid (<1%), sodium lauroyl sarcosinate (<3%), proprietary (3.5%). The pH listed on the safety data sheet is 6.0 +/− 0.5.

2.2. Sample Collection Method and Analysis

Hand Wipes

Hand wipe samples were collected after workers washed their hands with Cherry Bomb soap and water at the end of a workday after abrasive blasting a bridge coated with lead paint. The hand wipe testing was repeated the following day with the same participants after handwashing with Leadoff soap and water. American Society for Testing and Materials (ASTM) E1792 compliant hand wipes (Lead Wipe™) were used as the sample media. The workers were handed a Lead Wipe and instructed to wipe their palms first, followed by top surfaces of both sides of their hands for 30 seconds. Each hand wipe sample was placed into a pre-cleaned centrifuge tube and shipped to an American Industrial Hygiene Association (AIHA) accredited lab. One field blank (wipe sample media) was sent to the laboratory after each assessment. The laboratory reported no detectable lead on the field blanks. The wipe samples were analyzed in accordance with ASTM-E-1979/EPA SW846 7000B.

To ensure similar exposure both days during the assessment, the workers performed the same task for the same duration, wore the same personal protective equipment (PPE), and followed the same handwashing procedures (both process and duration). After the two-day handwashing assessment, the contractors only used Leadoff soap each day during handwashing for two consecutive months.

Personal Samples

Both contractors collected air samples on 37 mm, 0.8 μm pore size, mixed cellulose ester (MCE) filters using battery-operated sampling pumps (Gilian GilAir-3) at flow rates of 1.7 - 2.0 liters per minute. The pumps were calibrated with a primary calibration device. All personal samples were analyzed for lead via NIOSH Method 7082.

BLLs

Before exposure, and after two months using Leadoff soap, the workers' blood was drawn to measure the concentration of lead as part of each contractor's ongoing medical surveillance program. All lead-exposed workers (n = 44) participated in the BLL testing.

2.3. Worker Exposure Classification Scheme

To assist in rendering a judgment on the acceptability of the lead concentration of workers' hands after handwashing with Cherry Bomb and Leadoff soap for both exposure groups, we classified the hand wipe data using a Dermal Exposure Rating Scheme (see Table 1) adapted from the AIHA [12].

Table 1. Worker dermal exposure scheme (similar exposure group).

Rating	Description
0	95th percentile exposure < 1% of the DPEL
1	95th percentile exposure 1% - 10% of the DPEL
2	95th percentile exposure 10% - 50% of the DPEL
3	95th percentile exposure 50% - 100% of the DPEL
4	95th percentile exposure > 100% of the DPEL

2.4. Dermal Inorganic Lead PEL Dose Equivalent (DPEL)

We established a DPEL in order to evaluate the exposure data using the following formula provided by the AIHA [12].

$$\text{DPEL} = \text{PEL}\ (\mu g/m^3) \times 10\ m^3/\text{day inhaled air volume}$$

$$50\ \mu g/m^3 \times 10\ m^3 = 500\ \mu g/\text{shift}$$

2.5. Exposure Factors

Based on our experience evaluating industrial painting contractors' exposure controls, the concentration of lead to contact workers' hands during a work shift is high for both study exposure groups. These workers experience regular contact 50% to 100% of the shift.

2.6. Project Exposure Controls

Both of the contractors used recyclable steel grit as the blast media. Each project included the full enclosure of segments of the bridge with a containment system ventilated with a 45,000 cubic feet per minute rated portable dust collector All of the workers reported wearing a Type CE continuous flow (blast hood) respirator with an assigned protection factor of 1000, abrasive blasting coverall, and leather gloves. Although not common on some industrial painting projects, the laborers wore a Type CE continuous flow (blast hood) respirator because they vacuum inside the containment system during abrasive blasting.

2.7. Data Analysis

We performed statistical analyses using the American Industrial Hygiene Association's Multilingual IHSTAT + MS Excel application [13] and Expostats [14]. For the hand wipe sample with a lead concentration < the lab's detection limit (5 µg/wipe), we used a substitution method (analytical detection limit/2) proposed by Ganser and Hewett [15]. The data were assessed using the Shapiro-Wilk statistical test and the Expostats' graph entitled Q-Q plot. The hand wipe data were lognormally distributed. The data were log-transformed. Geometric mean (GM) and the geometric standard deviation (GSD) were calculated.

Descriptive statistical techniques were used to characterize the exposure distribution to assess if the lead concentration on workers' hands was reduced by using Leadoff. We also calculated the likelihood that the true 95th percentile lead concentration on workers' hands in an exposure group is >the study established DPEL to frame the statistical output from the wipe sampling data into probabilities that are more intuitive for contractors to measure the exposure acceptability.

3. Results and Discussion

3.1. Results

Lead on Workers' Hands

Thirty-four hand wipe samples were collected. Lead was detected in 33 out of the 34 samples. Table 2 presents a summary of the concentration of lead on workers' hands after washing with Cherry Bomb soap and water. The laborers had the most residual lead on their hands after handwashing. The 95th percentile lead concentration on workers' hands for both exposure groups was >the DPEL (500 µg/shift).

The likelihood that the true 95th percentile lead concentration on workers' hands is >DPEL (500 µg/shift) is 73.8% for the ABP group (see Figure 1) and 89.3 % for the laborer exposure group (see Figure 2).

Lead on Workers' Hands—Leadoff

Thirty-four hand wipe samples were collected. Lead was detected in all 34 samples. Table 2 presents a summary of the lead concentration on workers' hands after washing with Leadoff soap and water at the end of the workday. Laborers had the most residual lead on their hands at the end of the work shift compared with the ABP group. The 95th percentile lead concentration on workers' hands for both exposure groups was <DPEL (500 µg/shift).

For the ABP group, the GM lead concentration on the workers' hands decreased by 12 µg/hand wipe—a decrease of 18%. The arithmetic mean lead concentration on workers' hands decreased by 71 µg/hand wipe ($p = 0.02$). For the laborers, the GM lead concentration on the workers' hands decreased by 34 µg/hand wipe—a decrease of 26%. The arithmetic mean lead concentration on workers' hands decreased by 208 µg/hand wipe ($p = 0.36$). The use of Leadoff soap reduced the maximum lead exposure on workers' hands by 85% (1485 µg/hand wipe). The likelihood that the true 95th percentile lead concentration on workers' hands is ≤DPEL (500 µg/shift) is 99.6% for the ABP group (see Figure 1) and 90% for the laborer group (see Figure 2). An Aligned Rank Transform ANOVA test was performed to test differences between the two exposure groups. The p-value for the test of differences between the two exposure groups was 0.3.

Lead Personal Exposures

For the ABP group (n = 5), the GM exposure was 951 µg/m^3 (2.3 GSD) with a

Table 2. Lead concentration on workers' hands after washing.

Cherry Bomb	N	GM (SD) µg/hand wipe	Min µg/hand wipe	Max µg/hand wipe	95th %centile µg/hand wipe (UTL)	% > DPEL	Dermal exposure rating
All work classifications	34	77 (4.0)	2.5	1750	762 (1601)	5.9	4
ABP	26	65 (4.1)	2.5	658	664 (1623)	3.8	4
Laborer	8	130 (3.6)	23.4	1750	1077 (7806)	12.5	4
Leadoff	**N**	**GM (SD) µg/hand wipe**	**Min µg/hand wipe**	**Max µg/hand wipe**	**95th %centile µg/hand wipe (UTL)**	**% > DPEL**	**Dermal exposure rating**
All work classifications	34	61 (2.2)	11.5	265	226 (346)	0	2
ABP	26	53 (2.2)	11.5	209	201 (334)	0	2
Laborer	8	96 (1.8)	40.9	265	254 (634)	0	3

GM = geometric mean; SD = standard deviation; µg = microgram; Min = minimum; Max = maximum; UTL = upper tolerance limit.

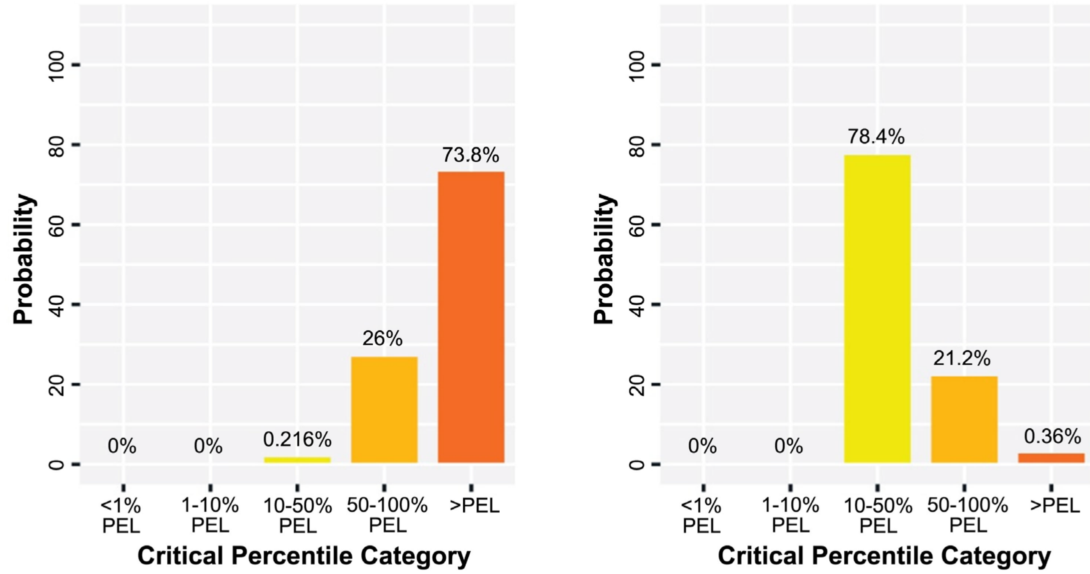

Figure 1. 95th percentile lead concentration on workers' hands. Probability distribution (abrasive blaster/painter) after handwashing with cherry. Bomb soap and water (Left) leadoff soap and water (Right). PEL = Dermal PEL.

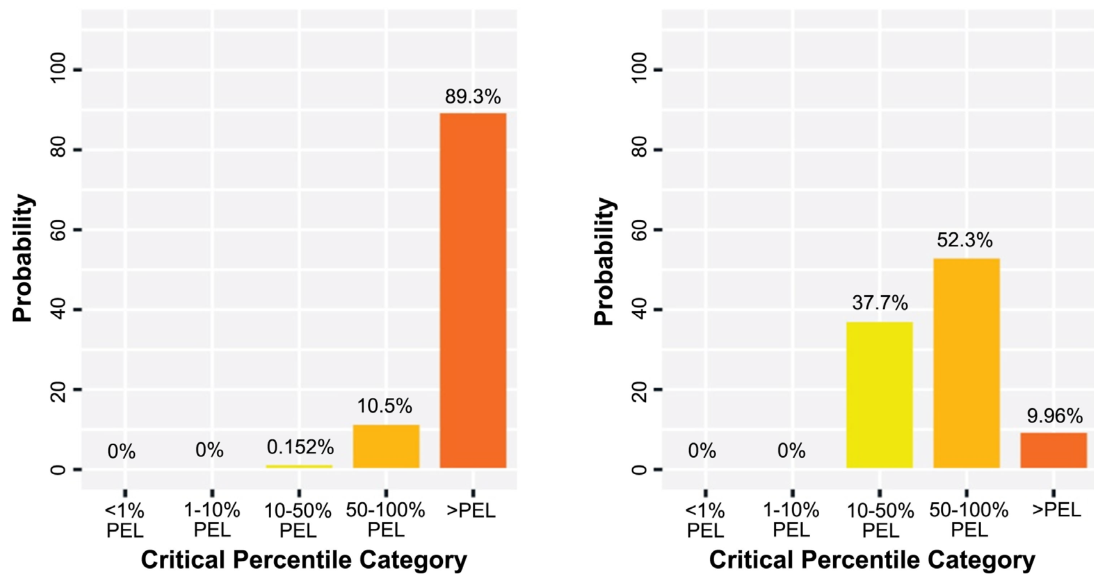

Figure 2. 95th percentile lead concentration on workers' hands. Probability distribution (laborers) after handwashing with cherry. Bomb soap and water (Left) leadoff soap and water (Right). PEL = Dermal PEL.

range from 350 μg/m³ to 3570 μg/m³. For the laborers (n = 2), the GM exposure was 8063 μg/m³ (3.5 GSD) with a range from 3300 μg/m³ to 19,700 μg/m³.

BLLs before Leadoff soap and water use

All of the laborers had BLLs < 25 μg/dl (see Table 3). Ten % (n = 4) of the ABP had a BLL ≥ 25 μg/dl. The maximum BLL observed for all work classifications before using Leadoff soap was 31 μg/dl.

BLLs after use of Leadoff soap

After workers washed their hands daily for two months with Leadoff soap, the

Table 3. BLLs before use of leadoff soap.

Work Tasks (Exposure Group)	N	GM (SD) BLL μg/dl	BLLμg/dl 95^{th} %centile	MIN μg/dl	MAX μg/dl
All work classifications	44	12.1 (1.8)	33.1	3	31
ABP	39	12.5 (1.8)	33.3	3	31
Laborer	5	9.5 (2.1)	34.9	3	20

BLL = Blood Lead Level; GM = Geometric Mean; SD = Standard Deviation; μg/dl = Microgram/Deciliter; Min = Minimum; Max = Maximum.

arithmetic mean BLLs increased by 5.8 μg/dl ($p < 0.01$) after 2-month follow-up for all work classifications. The arithmetic mean BLLs increased by 5.2 μg/dl ($p < 0.01$) for ABP ($p < 0.01$) while the laborers increased by 10.2 μg/dl ($p < 0.02$). The maximum BLL for all works tasks increased by 7 μg/dl. The 95th percentile BLL exposure profile for the ABP and laborer exposure groups were both > than 25 μg/dl (see **Table 4**). A repeated-measures analysis of variance to test differences across groups was performed. There was no significant difference between the ABP and Laborers ($p \le 0.87$).

3.2. Discussion

The objective of this study was to assess if Leadoff soap is more effective than a frequently used soap in the industrial painting industry in reducing the concentration of lead on workers' hands after exposure. Another aim was to assess if the use of Leadoff soap and water during handwashing reduces the uptake of lead among workers exposed in this population.

We found that Leadoff soap was more effective in removing lead from workers' hands than Cherry Bomb soap. We measured a significant reduction ($p < 0.02$) in the arithmetic mean lead concentration on workers' hands after workers washed their hands with Leadoff soap and water compared to the Cherry Bomb soap and water for the ABP group. The use of Leadoff soap reduced the 95th percentile lead concentration on workers' hands by 463 μg for the ABP group and by 823 μg for the laborer group compared to when the workers used the Cherry Bomb soap. The laborer group experienced lead concentrations on the workers' hands > the ABP group. This finding is consistent with the more intense airborne lead exposure reported for laborers.

We used an AIHA Dermal Exposure Classification Scheme [12] to assess the acceptability of the dermal exposure profile for each exposure group. After evaluating the 95th percentile lead concentration on workers' hands and the likelihood that the true 95th percentile dermal loading was >DPEL, we classified all exposure groups as having an unacceptable dermal exposure profile after using Zep and water during handwashing. In contrast, using the same criteria used to assess Zep, we classified all dermal exposure profiles as acceptable after the workers washed their hands with Hygenall and water at the end of the shift. There is less certainty regarding the acceptability of the labor dermal exposure profile as the 95th percentile upper tolerance limit exceeded the DPEL.

Table 4. BLLs after leadoff soap use.

Work Tasks (Exposure Group)	N	GM (SD) BLL μg/dl	BLL μg/dl 95^{th} %centile	MIN μg/dl	MAX μg/dl
All work classifications	44	18.1 (1.6)	38.7	6	38
ABP	39	17.9 (1.6)	38.2	6	38
Laborer	5	13.4 (2.0)	43.9	12	37

SD = Standard Deviation; μg/dl = Microgram/Deciliter.

The lead dermal exposure rating was reduced from category 4 to category 2 after the use of Leadoff soap for all work classifications and the ABP group. The laborer dermal exposure rating was reduced from category 4 to category 3 after using Leadoff soap during handwashing. As the contractors reported exposure intensity as consistent during the assessment period, the reduction of lead on worker's hands to the DPEL and 95th percentile for both exposure groups provide evidence of its utility as a risk management approach—especially the upper bound exposures. The contractors reported that the Bayesian likelihood plots (Figure 1 and Figure 2) were easy to understand and helped them more effectively communicate lead health risks to the workers while also making it easier for them to evaluate the exposure profile's acceptability. The contractors also reported the DPEL is a useful approach to measure compliance with existing lead paint removal requirements.

Worker BLLs increased despite the reduction in the lead concentration measured on workers' hands. We believe the most likely reason for this finding is ineffective inhalation exposure controls as the participating contractors reported failures in their enforcement of site exposure controls. The increase in BLLs despite a decrease in the concentration on workers' hands underscores the importance of evaluating both inhalation and ingestion exposure routes when determining the exposure profile's acceptability for an exposure group.

Our examination of the effectiveness of contractor's handwashing practices through the analysis of hand wipes provides evidence for the role work practice controls play in the prevention of the uptake of lead through ingestion exposure. Our research findings support the need for further research to gain a better understanding of the effectiveness of exposure controls.

A specific limitation associated with our study is there was not a practical way to verify that exposure controls were properly implemented by the participating contractors. An attempt was made to resolve this weakness by creating specific inclusion criteria to minimize the impact of this issue. Although the study is focused on exposure via the ingestion pathway, inhalation exposure could have contributed to the reported lead uptake; this may have been a confounding factor due to its effects on BLLs.

4. Conclusions

It would be prudent for contractors to adopt a DPEL to trigger changes in work practice controls to reduce unacceptable lead ingestion exposures. Despite OSHA's lack of specific guidance on the effectiveness of soap and water to remove lead from workers' skin, our research findings suggest contractors should use soap designed to remove lead from the skin in concert with appropriate PPE to reduce hand-to-mouth exposure risk. The lack of a DPEL to protect workers from lead exposure highlights a current gap in OSHA regulatory policy that needs to be addressed at an organizational level.

The use of a soap designed to remove lead from the skin is an effective risk management strategy that may form the basis for change to existing handwashing practices that can be used to reduce workplace exposure with minimal barriers for adoption. The information derived from our data analysis of BLLs and hand wipe lead levels could help prevent elevated BLLs on future bridge painting projects.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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