Review Article

Reducing occupational lead exposures: Strengthened standards for a healthy workforce

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\textbf{A B S T R A C T}

Outdated federal and state occupational lead standards leave workers and their families vulnerable to the adverse effects of lead. Standards should be updated to reflect the best available scientific and medical evidence, which documents harm to multiple organ systems even at low levels of exposure. This commentary will review the inadequacies of existing policies, highlight susceptible populations, and briefly summarize state revision efforts to date. Federal policies must be strengthened to protect all workers and their families from this well-documented hazard.

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1. Introduction

Lead poisoning returned to the national consciousness through the tragic events in Flint, Michigan, but drinking water is only one of many exposure routes. Outdated federal workplace safety standards allow for potential acute and chronic occupational lead exposure. While all workplace standards are traditionally less stringent than for exposures in the general public, the existing workplace standards for lead are dangerously inappropriate.

Lead is a well-studied metal toxicant with no known safe level of exposure (Centers for Disease Control and Prevention, 2017). Occupational exposure has long been linked to increased cancer and mortality (Anttila et al., 1995; Winegar et al., 1977; Gwini et al., 2012; Ilychova and Zaridze, 2012; Steenland et al., 1992, 2017; Stolley et al., 1991; Schwartz et al., 2005; Chowdhury et al., 2014). Yet even low lead levels in adults can cause numerous other adverse health outcomes, including hypertension, renal injury, cognitive impairments, and reproductive effects (Kosnett et al., 2007; National Toxicology Program, 2012). Workplace lead may also affect children, who can be exposed prenatally or through lead dust carried into the home (Newman et al., 2015; Hipkins et al., 2004; Whelan et al., 1997; Goyer, 1996; Silbergeld, 1991). The consequences of these exposures across the population are substantial. A recent analysis suggests that the combined direct and indirect costs of occupational lead in the United States are greater than $392 million annually (Levin, 2016).

We need to protect workers and their families from these significant adverse health effects and related financial costs by updating federal workplace lead standards based on the latest scientific research. Revising these standards, in addition to other outdated lead policies in this country (National Center for Healthy Housing, 2016; Bellinger et al., 2017), is essential to reducing harmful exposures across the population and meeting federal agency health goals.

2. Discussion

2.1. Existing standards provide inadequate protections

The U.S. Occupational Safety and Health Administration (OSHA) estimates that 804,000 general industry workers and

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838,000 construction industry workers are potentially exposed to lead through their jobs (Occupational Safety and Health Administration, Undated-b). While data from the state-based Adult Blood Lead Epidemiology and Surveillance (ABLES) Program indicate that there has been a substantial reduction in the prevalence of elevated adult blood lead levels (BLLs), workplace lead exposures are still a serious concern. Overall, approximately 94% of adults with elevated BLLs are exposed to lead in the workplace (Alarcon, 2016). There is likely substantial underreporting, however, given that not all employers provide BLL testing to their workers (even though this is a requirement of OSHA guidelines) and not all states participate in the ABLES program (Levin, 2016; Alarcon, 2016; Leigh, 2000). There is also no system in place to test and report BLLs of workers’ family members, and thus comprehensive data on take-home lead exposure are not available.

OSHA regulates workplace lead exposure at the national level through two standards: the general industry standard and the construction standard (29 CFR 1910.1025; 29 CFR 1926.62). While OSHA’s mandate is to “assure so far as possible every working man and women in the Nation safe and healthful working conditions” (Williams-Steiger Act, 1970) these goals have not been met for workplace lead exposure. Existing federal standards are severely outdated, based on information available in the 1970’s instead of the latest scientific and medical evidence. Selected inadequacies of the standards are outlined below.

2.1.1. Medical removal

Under the existing regulations, workers can be exposed to levels of lead that result in 60 micrograms (µg) of lead per deciliter (dL) of blood (or an average of 50 µg/dL on three or more tests) before medical removal is required, and they can return to work after their blood lead levels are as high as 40 µg/dL. As comparison, the Centers for Disease Control and Prevention (CDC) has set a “Healthy People 2020” national public health goal that aims to reduce the proportion of workers with blood lead levels above 10 µg/dL (US Office of Disease Prevention and Health Promotion, 2010) and has categorized a BLL > 5 ug/dL as “elevated” in the adult population (see graphical abstract, Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health, 2013; Occupational Safety and Health Administration, Undated-a; US Office of Disease Prevention and Health Promotion, 2010; Council of State and Territorial Epidemiologists (CSTE), 2009; National Institute for Occupational Safety and Health (NIOSH), 2017; National Notifiable Diseases Surveillance System (NNDSS), 2016; Association of Occupational and Environmental Clinics (AOEC), 2007; CDC Advisory Committee on Childhood Lead Poisoning Prevention, 2010; CDC, January 2017).

Exposure to levels of lead much lower than what is allowable under OSHA’s current standards have been linked to high blood pressure, decreased kidney function, reproductive effects and neurological impairments (Kosnett et al., 2007; National Toxicology Program, 2012). In particular, the National Toxicology Program Monograph on the Health Effects of Low-Level Lead concluded that there is “sufficient evidence” that BLLs <5 ug/dL are associated with decreased renal function and reduced fetal growth. There was also “sufficient evidence” that BLLs <10 ug/dL are associated with hypertension and essential tremor (National Toxicology Program, 2012). There is also a substantial body of literature linking occupation-related elevated blood lead levels to increased cancer and mortality (Anttila et al., 1995; Vinegar et al., 1977; Gwini et al., 2012; Ilychova and Zaridze, 2012; Steenland et al., 1992; Stollery et al., 1991; Schwartz et al., 2005; Chowdhury et al., 2014), and a recent multi-country cohort study adds to this evidence base by documenting an association between lead-exposed workers (with median BLL 26 ug/dL) and increased risk of lung cancer, chronic obstructive pulmonary disease (COPD), stroke, and heart disease (Steenland et al., 2017).

2.1.2. Air lead levels: standards & entry requirements

Equally problematic are the existing guidelines regarding allowable levels of lead in the air. Current regulations set a permissible exposure limit (PEL) of 50 µg/m³ averaged over 8 h for both general industry and construction. These levels were determined based on the goal of keeping worker BLLs below 60 µg/dL (43 CFR 1910.1025 1978). To keep worker BLLs below 10 µg/dL over a working lifetime – in line with current CDC Healthy People 2020 goals – models indicate that the PEL needs to be significantly lowered (California Department of Public Health, 2014).

The action level (AL), which triggers exposure monitoring and medical surveillance, is currently set as 30 µg/m³ averaged over an 8 h period. This level was set based on the goal of maintaining BLLs below 30 µg/100 g for individuals planning pregnancies (43 CFR 1910.1025 1978). However, current scientific evidence indicates that adverse reproductive effects occur at much lower BLLs (Kosnett et al., 2007). Therefore, this insufficient AL must also be updated.

The current air lead standards are unacceptably high for both the general industry standard and the construction standard, but additionally problematic is the overreliance on air lead levels to prompt action within general industry scenarios. Studies indicate that, at least in some circumstances, there is little correlation between air lead levels and BLLs (Richter et al., 1979; Lai et al., 1997; Lormpongs et al., 2003; Ho et al., 1998). Lead exposure through ingestion is likely responsible for the discrepancy in these measurements (Ho et al., 1998; Askin and Volkman, 1997; Ulenbelt et al., 1990; Cherrie et al., 2006). Therefore, the general industry standard must be updated to account for other routes of exposure by including alternative criteria for “entry” into the lead standard. For example, the standard could include specific “trigger tasks” or activities known to contain lead hazards that would automatically initiate monitoring and related protective measures for workers, analogous to what currently exists in the construction standard.

2.1.3. Training, hygiene, & risk communication

Improved lead education and safety training for the workplace are urgently needed. Employers should be responsible for providing designated lead-free areas for eating and drinking as well as changing areas for removal of lead-contaminated clothing to prevent take-home lead pathways. For example, lead-exposed shoes and boots should not be worn into the car or home. Frequent training in an appropriate and understandable format must be provided to employers, and clear warnings signs should be located in areas containing lead hazards. Protective equipment should be provided whenever lead is present, instead of the current protocol that only requires protective clothing and shoes when lead is present above the PEL (29 CFR 1910.1025). The overarching concept that there is no safe level of lead exposure, especially for children, needs to be emphasized in all risk communication.

2.2. Vulnerable populations

ABLES data indicate that industries with high potential for occupational lead exposure include manufacturing, construction, services, and mining. Table 1 lists specific trades within each of these industries that accounted for the highest percentage of reported occupational lead exposure cases in 2013 (Alarcon, 2016).

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Another problematic industry is indoor firing ranges, which represent important sources of lead exposure for workers as well as individuals participating in target practice (Laidlaw et al., 2017). There are estimated to be between 16,000–18,000 indoor firing ranges in the United States (Beaucham et al., 2014). Lead-based projectiles can result in immediate and significant airborne lead concentrations, and settled lead dust that is improperly cleaned can present a delayed hazard even after active shooting practice has ceased (Beaucham et al., 2014; National Shooting Sports Foundation, 2011).

In these and other industries, not only are workers at risk, but their families may also be exposed inadvertently through take-home lead dust (Newman et al., 2015; Hopkins et al., 2004; Whelan et al., 1997; US Department of Health and Human Services, 1995; Baker et al., 1977; Centers for Disease Control and Prevention, 2012a; Aguilar-Garduño et al., 2003; Roscoe et al., 1999). In a meta-analysis by Roscoe et al. (1999), the authors concluded that there were at least 48,000 families with young children and household individuals subject to take-home lead from occupational exposure. Their limited data suggested that approximately 50% of the young children in these families had BLLs greater than 10 µg/dL. This analysis, albeit dated, indicates that occupational lead exposure presents risks for lead exposure in children. Further work is urgently needed to quantify the current frequency and magnitude of take-home exposures.

Children are particularly vulnerable to lead, since they absorb a greater percentage of the metal from the gastrointestinal tract compared to adults (Lidsky and Schneider, 2003). Because lead substitutes for calcium, children, pregnant or lactating women, and individuals with nutritional deficiencies exhibit increased absorption (Lidsky and Schneider, 2003; Ettinger et al., 2009). Children’s developing nervous systems are highly susceptible to the effects of environmental toxicants (Grandjean and Landrigan, 2006), and even low level lead exposure can result in long-term intellectual impairment (Lanphear et al., 2005; Needleman et al., 1990; Bellinger et al., 1992; Centers for Disease Control and Prevention, 2012b). The economic and societal implications of lead exposures across the population are significant and have been discussed previously (Gilbert and Weiss, 2006).

Women working in industries with potential lead exposure are themselves at risk for adverse effects from lead (Koşnett et al., 2007), and they may also be putting the next generation at risk. Lead released from bones during pregnancy easily crosses the placenta (Silbergeld, 1991), and children born to lead-exposed workers experience neurodevelopmental and other adverse health effects (Goyer, 1996; Schnaas et al., 2006).

It should also be noted that the Fair Labor Standards Act has set 14 years of age as the general minimum age of employment (29 CFR 570.2). Certain types of hazardous work are prohibited for individuals under the age of 18 years of age, but situations with high risk of lead exposure are not explicitly listed in this regulation (29 CFR 570.50–68). The potential for adolescent exposure to such high levels of lead is very concerning, given that even low lead exposures (below 10 µg/dL) have been associated with cognitive deficits (Lanphear et al., 2000). Furthermore, the brain continues to undergo crucial development through young adulthood (Casey et al., 2000; Sowell et al., 1999) – and thereby can remain vulnerable to disruption from lead exposure.

Additionally, preliminary reports suggest that occupational exposure may occur disproportionately among minority communities. In King County (Seattle, WA), Asian, Hispanic, and other workers of color are more likely to be exposed to high levels of lead through the workplace (Karasz, 2016; Public Health King County, 2016). For example, while the 2010 U.S. Census indicates that only 6.8% of Seattle residents are Hispanic/Latino (City of Seattle Office of Planning and Community Development, 2010), a recent analysis indicates almost one third of workers exposed to lead through bridge painting were Hispanic (Hayes, 2016). These disproportionate exposures further emphasize the need for changes to the existing standards.

### 2.3. New state standards on the horizon

OSHA sets minimum national standards for worker lead exposure, but these standards can be superseded if a state has an occupational safety and health program. Currently, 22 states have OSHA-approved state plans, including California and Washington. However, currently, these state standards are identical to the insufficient federal standards. Recognizing the need for improved protections, both California and Washington are in the process of updating their state occupational lead standards. The California Department of Public Health Occupational Lead Poisoning Prevention Program conducted extensive research on the latest scientific and medical literature and made specific recommendations for improvements in 2010 and 2011. Their guidance includes: lowering the BLL for medical removal to two BLLs above 20 μg/dL or one BLL above 30 μg/dL; increasing the frequency of BLL testing; triggering BLL testing based on activities that create lead hazards instead of the results of air monitoring; and lowering the PEL to 0.5–2.1 μg/m³ averaged over an 8-h workday (California Department of Public Health, 2014). The latter recommendation regarding the lower PEL was based on a report produced by the Office of Environmental Health Hazard Assessment (OEHHA), California Environmental Protection Agency (Cal/EPA) that used an updated physiologically-based pharmacokinetic (PBPK) model to characterize the relationship between air lead levels and blood lead levels (Vork et al., 2013). After over six years and a series of advisory meetings to receive feedback on discussion draft updates, it appears that California has still not completed the process to promulgate revised standards.

Washington State has begun a similar process. In 2012, Public-Health Seattle & King County (PHSKC) petitioned Governor Jay Inslee and the Washington State Department of Labor & Industries (L&I) to update the state’s outdated occupational lead standards. Drawing on much of the same research conducted to support California’s update process, PHSKC has developed recommendations to ensure that worker BLLs remain below 10 µg/dL over a working lifetime. These recommendations include: reductions in air lead levels that trigger regulatory actions, to an AL of 2 µg/m³.
and a PEL of 10 \( \mu \text{g}/\text{m}^3 \); lowering the BLL that triggers medical removal to two BLLs above 20 \( \mu \text{g}/\text{dL} \), or one BLL above 30 \( \mu \text{g}/\text{dL} \); improved medical monitoring for lead-related health effects; stricter standards for protective clothing, hygiene, training, and education (Hayes, 2016). L&I released a draft first of their updated regulations in summer 2017 and is currently considering stakeholder feedback in a revision process. Key aspects of their initial draft include an AL of 10 \( \mu \text{g}/\text{m}^3 \), a PEL of 20 \( \mu \text{g}/\text{m}^3 \), a chronic removal BLL of 20 \( \mu \text{g}/\text{dL} \), and an acute removal BLL 30 \( \mu \text{g}/\text{dL} \).

3. Conclusion

3.1. Scientific considerations

Scientifically, it is well established that even low levels of lead exposure can cause lifelong damage to the neurologic system and can lead to complications for numerous other organ systems (Kosnett et al., 2007; National Toxicology Program, 2012). Previous literature – including a Congressional report – has demonstrated that workers exposed to lead on the job can bring lead into the home on their clothing, thereby exposing their families (Newman et al., 2015; Hipkins et al., 2004; Whelan et al., 1997; US Department of Health and Human Services, 1995; Baker et al., 1977; Centers for Disease Control and Prevention, 2012a; Aguilar-Garduño et al., 2003; Roscoe et al., 1999). Given that children exhibit higher absorption of lead than adults (Lidsky and Schneider, 2003), that their developing organ systems are highly susceptible to the adverse health effects of all chemicals (Lindsay and Goldman, 2011), and that early life lead exposure can have long term consequences (Needleman et al., 1990; Reuben et al., 2017; Bellinger, 2017), it is critical that occupational lead regulations consider not only the health of workers but also of their young family members.

3.2. Historical considerations

Decades of data document the adverse effects of lead across the population, and this information has resulted in a dramatic drop in the acceptable childhood blood lead level (see Fig. 1). One driving factor for these changes has been the recognition that the most serious consequences of childhood lead exposure are its neurologic effects. Unfortunately, however, despite the scientific and medical information on the harmful effects of lead in adults, the occupational standards have not been changed in over forty years. Analagous to standards for the rest of the population, occupational exposure standards should also be updated regularly in accordance with new scientific evidence.

3.3. Ethical considerations

Everyone has a right to a lead-free environment that allows him/her to reach and maintain his/her full potential. As described above, occupational lead exposure can have direct adverse health effects on exposed workers. Yet, occupational lead exposures may also cause adverse health effects on family members and future generations. For example, when parents or young adult workers bring workplace contamination into the home, they can expose their families and children to lead. In addition, though the consequences have yet to be fully elucidated, lead exposure has been linked to epigenetic changes (Ruiz-Hernandez et al., 2015). Further work is needed to better understand the intergenerational implications of lead exposure, but this potential suggests the need for epiprecaution (Gilbert, 2016).

Overall, CDC has determined there is no safe level of blood lead for children (Centers for Disease Control and Prevention, 2017), and recent research documents the hazards to adults from even low levels of lead (< 10 \( \mu \text{g}/\text{dL} \)) (National Toxicology Program, 2012). With this scientific knowledge comes ethical and political responsibility. Scientists and health professionals are fully aware of the hazards of lead for children and adults, and we must now press for standards that are protective for the entire population.

3.4. National action needed

The existing occupational lead standards are so outdated that some private companies have actually implemented more protective standards for their own employees (Dupont, 2016). The state-specific actions in Washington and California, as described above, are important, but why should workers in only two states be privileged to improved health protections? OSHA standards should also be strengthened to adequately protect workers and families across the country, as all individuals have a right to a healthy and safe work environment. The American College of Occupational and Environmental Medicine (ACOEM) recently released a position statement endorsing updated occupational lead standards for all American workers (Holland and Cawthon, 2016).

Adapted from Gilbert and Weiss (2006).

**Fig. 1.** Decrease in Acceptable Childhood Blood Lead Levels.

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We have the scientific and medical evidence that documents the harms of elevated blood lead levels, and we have the technology to reduce occupational lead exposure. Now is the time to take action by:

- Adopting an occupational lead standard that is aligned with CDC's existing public health guidance;
- Ensuring that OSHA receives sufficient financial support for necessary enforcement actions;
- Implementing routine BLL testing for family members of workers at risk for occupational lead exposure.

Updated federal occupational standards are a critical component of broader, nationwide efforts to reduce lead exposure across the general population, such as through improvements to existing regulations related to residential property and drinking water. Stronger standards for all lead-related policies will ensure a stronger, healthier generation for generations to come.

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