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Assessment of blood lead level declines in an area of historical mining with a holistic remediation and abatement program

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ABSTRACT

Lead exposure and blood lead levels (BLLs) in the United States have declined dramatically since the 1970s as many widespread lead uses have been discontinued. Large scale mining and mineral processing represents an additional localized source of potential lead exposure in many historical mining communities, such as Butte, Montana. After 25 years of ongoing remediation efforts and a residential metals abatement program that includes blood lead monitoring of Butte children, examination of blood lead trends offers a unique opportunity to assess the effectiveness of Butte's lead source and exposure reduction measures. This study examined BLL trends in Butte children ages 1–5 ($n=$ 2796) from 2003–2010 as compared to a reference dataset matched for similar demographic characteristics over the same period. Blood lead differences across Butte during the same period are also examined. Findings are interpreted with respect to effectiveness of remediation and other factors potentially contributing to ongoing exposure concerns.

Reference population comparison: BLLs from Butte were compared with a reference dataset ($n=2937$) derived from the National Health and Nutrition Examination Survey. The reference dataset was initially matched for child age and sample dates. Additional demographic factors associated with higher BLLs were then evaluated. Weights were applied to make the reference dataset more consistent with the Butte dataset for the three factors that were most disparate (poverty-to-income ratio, house age, and race/ethnicity). A weighted linear mixed regression model showed Butte geometric mean BLLs were higher than reference BLLs for 2003–2004 (3.48 vs. 2.05 μg/dL), 2005-2006 (2.65 vs. 1.80 μg/dL), and 2007-2008 (2.2 vs. 1.72 μg/dL), but comparable for 2009–2010 (1.53 vs. 1.51 μg/dL). This trend suggests that, over time, the impact of other factors that may be associated with Butte BLLs has been reduced.

Comparison across Butte: Neighborhood differences were examined by dividing the Butte dataset into the older area called "Uptown", located at higher elevation atop historical mine workings, and "the Flats", at lower elevation and more recently developed. Significant declines in BLLs were observed over time in both areas, though Uptown had slightly higher BLLs than the Flats (2003–2004: 3.57 vs. 3.45 μg/dL, $p=0.7$; 2005–2006: 2.84 vs. 2.52 μg/dL, $p=0.1$; 2007–2008: 2.58 vs. 1.99 μg/dL, $p=0.001$; 2009–2010: 1.71 vs. 1.44 μg/dL, $p=0.02$). BLLs were higher when tested in summer/fall than in winter/spring for both neighborhoods, and statistically higher BLLs were found for children in Uptown living in properties built before 1940. Neighborhood differences and the persistence of a greater percentage of high BLLs (> 5 μg/dL) in Butte vs. the reference dataset support continuation of the home lead abatement program.

Conclusions: Butte BLL declines likely reflect the cumulative effectiveness of screening efforts, community-wide remediation, and the ongoing metals abatement program in Butte in addition to other factors not accounted for by this study. As evidenced in Butte, abatement programs that include home evaluations and assistance in addressing multiple sources of lead exposure can be an important complement to community-wide soil remediation activities.

1. Introduction

Over the past four decades, blood lead levels (BLLs) have declined dramatically as bans on leaded gasoline and lead in paint, plumbing, and solder for canned foods have spread around the world; however, higher BLLs persist among some individuals,

Abbreviations: BLLs, Blood Lead Levels; BSB, Butte-Silver Bow; CDC, Centers for Disease Control and Prevention; NHANES, National Health and Nutrition Examination Survey; PIR, Poverty-to-Income Ratio; WIC, Women, Infants, and Children

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including potentially those people who live in close proximity to some historical mining operations (Boreland et al., 2008; Kim et al., 2012; Lanphear et al., 2003; Park et al., 2014; Taylor et al., 2014; Zhang et al., 2012). Only rarely have remediation and abatement efforts been demonstrated to reduce BLLs in these communities (Boreland et al., 2008; Hilts et al., 1998; National Research Council, 2005; Sheldrake and Stifelman, 2003). Boreland et al. (2008) conclude that soil stabilization and storm water controls, along with home remediation and health promotion, were effective in reducing BLLs in the Broken Hill community in New South Wales, Australia between 1991 and 2007, and Sheldrake and Stifelman (2003) describe the effectiveness of a community-wide, preventative approach in a former smelter community in Idaho.

Butte, Montana was the center of copper mining in North America during the late 1800s and by the early twentieth century had more than 450 mines (U.S. Environmental Protection Agency, 2014). Mine waste dumps and overburden piles were interspersed with residential areas throughout the older parts of the community. The Butte Area site, with a boundary spanning from the Continental divide west along Silver Bow Creek to the Warm Springs Ponds, was placed on the United States (U.S.) Superfund National Priorities List in 1983. Cleanups of mine wastes in Butte occurred between 1988 and 2004 with a focus on stabilizing, capping, or removing hundreds of thousands of cubic yards of waste and contaminated soil from waste dumps and residential yards and installing sedimentation ponds to address stormwater runoff (U.S. Environmental Protection Agency, 2014). Most of the planned long-term cleanup and restoration activities have been completed, including redevelopment and reuse projects that resulted in public parks, activity centers, and extensive walking/biking trails for the community; however, residential lead abatements are still ongoing.

An exposure study performed in 1990 by the Butte-Silver Bow (BSB) Health Department and the University of Cincinnati identified statistically significant differences in children's BLLs across selected areas of Butte (Butte-Silver Bow Department of Health and University of Cincinnati, 1992). The overall geometric mean BLL for Butte children, 3.5 μg/dL, was not found to be elevated relative to typical BLLs at that time in the U.S.; however, no formal analysis comparing Butte BLLs with those of a comparable reference dataset was performed. The 1990 study included collocated measures of soil and house dust concentrations, measures of lead in tap water, lead paint assessments, and administration of a questionnaire on household lead sources and socioeconomic information. Children from older neighborhoods where soil concentrations were more likely to be affected by both mining and non-mining related lead sources had higher geometric mean BLLs (3.7–4.6 μg/dL) than children from more recently developed neighborhoods (2.3–3.0 μg/dL).

The 1990 study showed that residence location (i.e., neighborhood area) and house age were the strongest predictors of paint lead, soil lead, and dust lead concentrations in Butte. Lead-based paint was shown to be associated with lead contaminated soil, which in turn was associated with lead contaminated house dust. Only house dust lead was directly related to blood lead. The indirect effect of soil lead on blood lead was shown to be both small and weak: only 5.4 percent of variance in blood lead was found to be indirectly attributable to lead in soil. The investigators concluded that 39 percent of the variability in soil lead concentrations was attributable to lead-based paint, while the remainder (61 percent) was attributable to "the heterogeneous distribution of lead in soil, and lead from other sources such as native lead in soil, mine waste, and contaminates from ore processing". Gardening or eating home grown produce did not contribute to elevated BLLs.

Based on the 1990 study findings, the University of Cincinnati investigators recommended the development of a program in Butte to identify and address residential lead exposure from all sources. From this early program came the current, ongoing, multi-pathway residential metals abatement program, designed to mitigate harmful exposure to lead, arsenic, and mercury in the Butte Priority Soils Operable Unit and an adjacent area. This program works in conjunction with the BSB Health Department and the state's Women, Infants, and Children (WIC) program, which has provided free blood lead testing to thousands of children over the past decade. Any child with a high blood lead is referred to the residential metals abatement program (Butte-Silver Bow County, Atlantic Richfield Company, 2010). The program then performs a home evaluation to identify the source of lead, including sampling for indoor dust, outdoor soil, indoor and outdoor paint, and lead in drinking water (from plumbing). Based on a series of criteria, varying levels of abatement are then performed at the property. As of 2013, the program has sampled approximately 2340 of the 3646 properties (64 percent) included within the program's target area and performed abatement events at more than 500 properties. The soil lead cleanup of 1200 mg/kg was based on a risk assessment and bioavailability studies showing low relative bioavailability of lead in Butte soil (U.S. Environmental Protection Agency, 2006). In addition to environmental assessments and abatements, the county also offers community educational resources.

The objective of this study was to examine BLL trends in Butte children ages one through five from 2003 to 2010 as compared to a reference dataset matched for similar demographic characteristics over the same period. Children of this age range were the focus because they are a vulnerable population and are known to have higher BLLs than older children and adults (Bellinger, 2004). Because the 1990 lead exposure study found significant differences in BLLs across Butte neighborhoods, this study also examined child blood lead differences across Butte neighborhoods from 2003 to 2010. Results of both analyses are interpreted with respect to effectiveness of remediation and other factors potentially contributing to ongoing exposure concerns.

A variety of demographic and socioeconomic factors are known to correlate with BLLs in children. Development of a reference dataset requires consideration of the relative importance of these factors, as well as the variation in these factors between the target and reference datasets. Major factors associated with higher BLLs include child age, race/ethnicity, socioeconomic status, and house age (Centers for Disease Control, 2013a, 2000; Gee and Payne-Sturges, 2004; Jones et al., 2009; Levin et al., 2008; Sargent et al., 1995). Higher BLLs in 2-3 year old children are thought to be associated with greater hand-to-mouth activity and other behaviors associated with this age range (ACCLP, 2012; Gaitens et al., 2009). The reasons why BLLs vary with race/ethnicity and socioeconomic status are less clear. Older house age is also associated with higher geometric mean BLLs (Alder et al., 1993; Kim et al., 2002). The prevalence of lead-based paint in U.S. housing is higher in housing built before 1940 than in housing built in subsequent decades, leading up to the ban of lead-based paint in such housing in 1978 (U.S. Consumer Product Safety Comission, 1977; U.S. Department of Housing and Urban Development, 2001). Older houses are more likely to have higher lead-based paint concentrations and deteriorated paint surfaces that increase exposure potential. Plumbing with lead pipes or solder or lead-containing fittings is also more likely to be present in older homes; lead was banned from plumbing in 1986 (U.S. Environmental Protection Agency, 1989). Many other lead sources have also been associated with higher BLLs, including crystal glassware and ceramic dishes, chocolate and imported foods and spices, traditional medicines, old vinyl mini-blinds and other vinyl products, a broad range of children's products and toys, and hobbies using lead solder (e.g., making

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