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A Comparison of Occupational Blood Lead Level (BLL) Prevalence and Airborne Lead Concentration in Utah and Nationally

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ABSTRACT

The healthy people 2010 lead objective sought to reduce the number of employees occupationally exposed to lead with Blood Lead Levels (BLLs) ≥ 25 µg/dL to 0. Concurrently, occupational limits have been set at 50 ug/m^3 for lead in the air. To determine whether Utah and the U.S. met these prior national goals, this retrospective study compared elevated BLL prevalence from Utah and U.S. employees from 2000-2009 against the healthy people 2010 goal. Lead air concentrations were also compared against U.S. Occupational Exposure Limits (OELs). Results found that elevated BLL prevalence statistically significantly declined for both Utah and the nation but did not reach the intended goal of healthy people 2010. Lead air concentrations similarly declined but were higher than proposed OELs, suggesting additional research is needed.

Keywords: BLLs; Air concentrations; Demolition; Public health; Reproductive systems

INTRODUCTION

Occupational exposure to lead continues to threaten worker health, with an estimated 1.6 million workers regularly exposed to lead [1]. The construction industry accounts for nearly half of these, as these workers frequently perform demolition, renovation, and remediation of buildings constructed prior to the banning and widespread discontinuation of lead based paint in the 1970's [2]. Two other industries at risk for lead exposures are metalworking (melding and manufacturing) and the manufacturing of lead acid batteries, the latter of which accounts for 70% of the lead used in the United States today [3,4]. In these industries, the primary exposure route of lead is through inhalation [5]. While lead exposures are sometimes resolved through a natural excretion process, if the level of intake is higher than the rate of excretion, it can cause Blood Lead Levels (BLL) to rise. In the U.S., 95% of elevated BLL (defined as ≥ 25 µg/dL) in adults are associated with work related exposures.

Lead is associated with numerous adverse health effects and considerable financial costs. The health impacts of lead exposure range broadly from impairments to daily functioning (e.g. depression and poor concentration) to damage to the cardiovascular, nervous, kidney, and reproductive systems. One estimate in 2016 found that while the direct medical costs associated with occupational lead exposure were $141 million, including the indirect costs due to lost work time and productivity brought the total as high as $392 million [6]. In fact, the true costs of occupational lead exposure may be higher, as any exposure to lead at work can also lead to employees carrying lead contamination home.

Reducing exposure to lead has become a leading occupational safety priority. OSHA concurs with recommended exposure limits from the National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH), which are all set at 50 µg/m^3 for an 8 hour shift [7-9]. However, there is a considerable discrepancy between regulations and

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recommendations in terms of BLL. In 2015, in response to additional research on associations between lead exposure and increased mortality by cardiovascular disease and cancer, NIOSH reduced the maximum recommended adult BLL to 5 µg/dL [10-12]. However, OSHA regulations require only that employees with BLLs ≥ 50 µg/dL (for the construction industry) and ≥ 60 µg/dL (for general industry) be removed from work until their levels have decreased to ≤ 40 µg/dL [13]. Given that both general scientific consensus and that NIOSH's recommendations are substantially lower, such regulations may result in at risk occupational populations experiencing high levels of exposure.

Several surveillance programs have been instituted to monitor occupational lead exposure, but air levels and BLL are tracked separately. OSHA records air sample results into the Chemical Exposure Health Data (CEHD), which includes personal, area, and bulk air samples on various toxic agents, including lead air levels [14]. NIOSH's Adult Blood Lead Epidemiology and Surveillance (ABLES) program tracks laboratory-reported BLLs in adults that are occupationally exposed to lead. The most recent ABLES data (2016) for 26 out of the participating 37 states puts the prevalence of BLLs ≥ 25 µg/dL at 2.8 per 100,000 employed adults 16+ years old, and the prevalence for BLLs ≥ 10 µg/dL at 15.8 per 100,000 working adults 16+ years old [15]. These data are a key source of information for Healthy People, a nationwide initiative by the U.S. Department of Health and Human Services (DHHS) that seeks was to reduce the number of employees occupationally exposed to lead with BLLs ≥ 25 µg/dL to 0.16 [16,17]. As of 2020, 41 states contribute to the ABLES program, which requires that participating states share all BLL data. However CEHD and ABLES have not yet been combined for analysis.

To examine the efficacy of lead exposure recommendations and regulations, this study compares BLL prevalence in the state of Utah and nationwide using the healthy people 2010 goal and timeline (2000-2009) as a benchmark: Prevalence per 100,000 employed adults with BLLs ≥ 25 ug/dL for each year in both Utah and the nation. Air concentrations from the same period in the CEHD will be compared with national BLL prevalence and U.S. Occupational Exposure Limits (OELs). Utah was chosen for state level analysis because Utah has multiple industries where workers risk lead exposure (an estimated 236,030 jobs, or 16.2% of the employed population), including smelting and refining of metals, power plant activity, and mine tailings. We hypothesize that:

- There was a statistically significant decrease in the prevalence of elevated BLL between the years 2000 and 2009 for workers in the state of Utah and the U.S. as a whole.
- That this decrease coincides with a decline in reported lead air concentration levels.

MATERIALS AND METHODS

To determine the changing prevalence of employed adults with BLLs ≥ 25 ug/dL, a retrospective investigation was conducted using data from the national ABLES dataset from the years 2000-2009 and Utah's Environmental Public Health Tracking Network (EPHTN), Utah's contribution to the ABLES program. BLL data are collected through local clinical laboratories and are reported on a weekly or monthly basis, then stored in the Utah Blood Lead Registry (UBLR).

A secondary analysis examined the same time frame, but compared the ABLES dataset to OSHA's CEHD to determine if the change in elevated BLL prevalence was associated with any change in lead air concentration. As these data are public and de-identified, no Institutional Review Board (IRB) approval was required.

All BLL data was from either the Utah EPHTN or the ABLES dataset and collected between the years of 2000-2009. BLLs from unemployed adults and children were excluded. Lead air concentrations between 2000-2009 from OSHA's CEHD were also extracted. Only data from personal samplers with concentration values listed in mg/m^3 were included from CEHD.

Data from the EPHTN and ABLES dataset were available in Excel (Microsoft, Redmond, WA) format and did not require cleaning. Data extracted from the CEHD were cleaned and converted to Excel for analysis in SAS 9.4 (SAS Institute, Cary, NC). The OSHA data cleaning application process, which included removal of all blanks, duplicates, and erroneous data, was used.

After this process, more than 20% of the CEHD data (per year) still contained multiple concentrations measured below the limit of detection that prohibited statistical analysis. An iterative approach was therefore used to estimate the measured amount of lead in the air for each non-detectable concentration. This was accomplished by using the "ND Expo–Treatment of non-detects in industrial hygiene samples" web application. As this application requires that at least 20% of the data be detectable sample, the 2009 lead concentration year (which had 18% of detectable data) was excluded from analysis.

All datasets were tested for normality using the Shapiro-Wilks test (W-statistic). As the data were found to be normally distributed, parametric tests were then used to generate a time series for each dataset throughout the decade. To investigate the presence of declines in high BLL prevalence in Utah and the nation, and statistically significant reductions in national air lead concentrations for the period, linear regressions were generated for each variable. For all analyses, an alpha level of 0.05 was used. Finally, linear regression was used to compare:

- Utah's BLL prevalence to the nation's BLL prevalence.
- Nation's BLL prevalence to lead air concentration.

RESULTS

Both the national and Utah BLL prevalence per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL between declined between 2000-2009 (**Figure 1**) from 11.9 in 2000 to 6.3 in 2009.

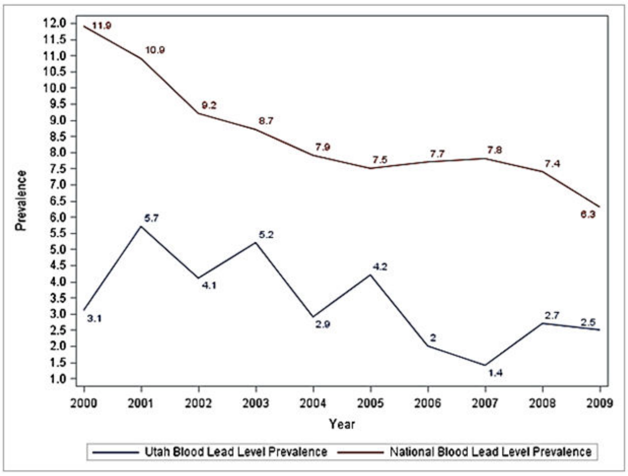

Figure 1: Time series from 2000-2009 for elevated BLL prevalence* in Utah and the U.S.

*Per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL.

However, national mean lead air concentrations were recorded above the OEL every year between 2000-2008 (**Figure 2**). Average lead air concentration peaked in 200 at 1.15 mg/m^3, but decreased afterwards with a low of 0.086 mg/m^3 in 2005.

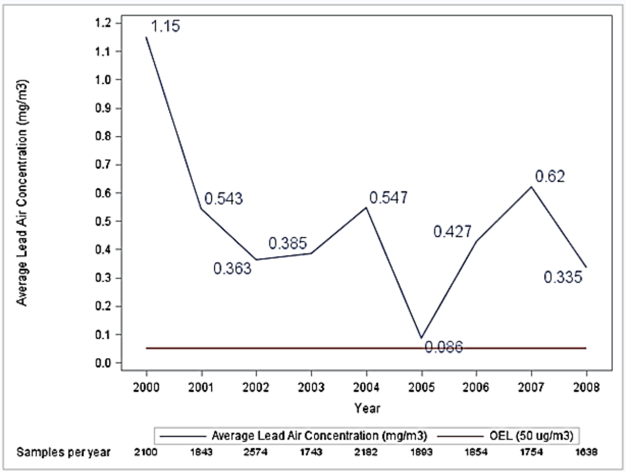

Figure 2: Time series from 2000-2008 for mean lead air concentration in the U.S.

The nation's BLL prevalence had an overall decline of 0.517 per year, with an R^2 of 0.84 and p-value of 0.0002 (alpha 0.05) (**Figure 3**) suggesting that time accounts for the variance in national BLL prevalence.

Utah's elevated BLL prevalence, conversely, maintained a pattern of rising and falling until 2007, when the prevalence decreased to 1.4 per 100,000 employed adults 16+ years old (**Figure 4**). Utah's high BLL prevalence decline was 0.292 per year, with a weak R^2 of 0.41. The linear regression's slope p-value (**Table 1**) was 0.0468, demonstrating statistical significance.

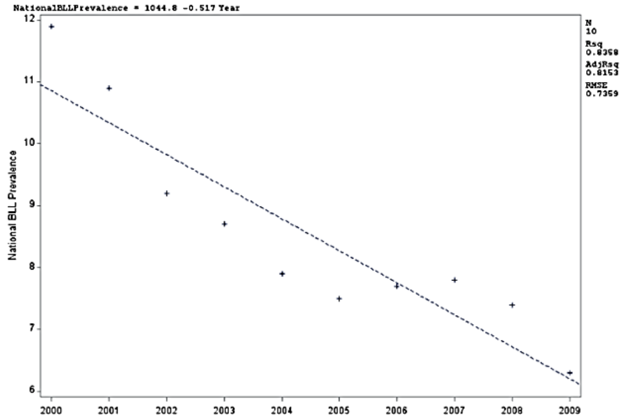

Figure 3: Linear regression between Years 2000-2009 and national high BLL prevalence.

*Per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL.

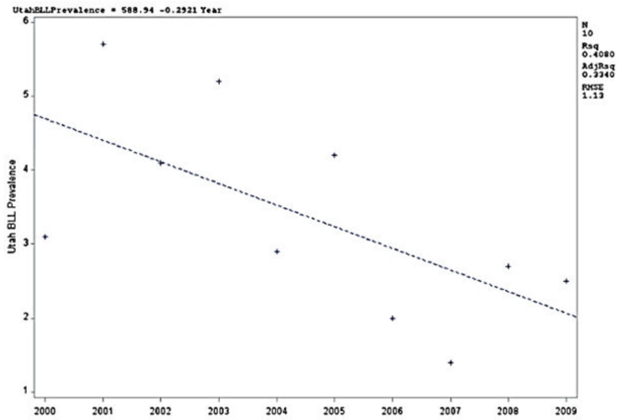

Figure 4: Linear regression between years 2000-2009 and Utah high BLL prevalence.

*per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL.

The mean air lead concentration over time (**Figure 5**) was estimated to decline 0.053 mg/m^3 per year; however, the R^2 value was 0.25, while the slope's p-value was 0.1680 (**Table 1**), indicating that the slope is not significantly declining. Although the model was able to predict a decline in air lead concentration, the high p-value and low R^2 suggest that more information is needed to improve the model.

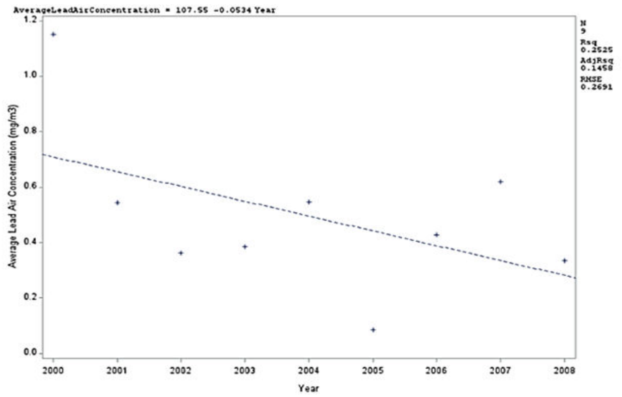

Figure 5: Linear regression between years 2000-2008 and mean air lead concentration.

Table 1: Slope and p-value for the three linear regressions over time.

Dataset	Slope	p-value
Utah BLL prevalence	-0.2921	0.0468
National BLL prevalence	-0.517	0.0002
Average air lead concentration	-0.0534	0.168

Note: BLL: Blood Lead Level.

Figure 6 is the linear regression comparing Utah's high BLL prevalence to the nation's high BLL prevalence from 2000-2009. To predict Utah's BLL prevalence from national prevalence, it was decided that the national BLL prevalence would be the x-variable with Utah's BLL prevalence as the y-variable. This setup seems more practical to estimate individual state prevalence from a single dataset such as ABLES. Setting the regression in this way demonstrates a 0.38 prevalence increase in Utah to a single prevalence increase in the nation. But the model has a very weak R^2 of 0.23, suggesting it is not appropriate for prediction.

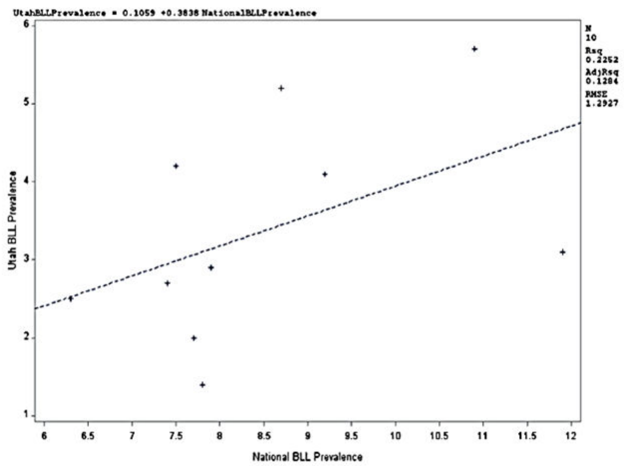

Figure 6: Linear regression between national and Utah high BLL prevalence* from 2000-2009.

*Per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL.

The linear regression plot comparing national high BLL prevalence (y-axis) and national average air concentration (x-axis, listed at mg/m^3) can be seen in **Figure 7**. Every 1.0 mg/m^3 increase in lead air concentration corresponded to an estimated four additional cases per 100,000 employed adults with BLLs ≥ 25 ug/dL. The model has a moderate R^2 of 0.536, advising caution if to be used for predictive purposes.

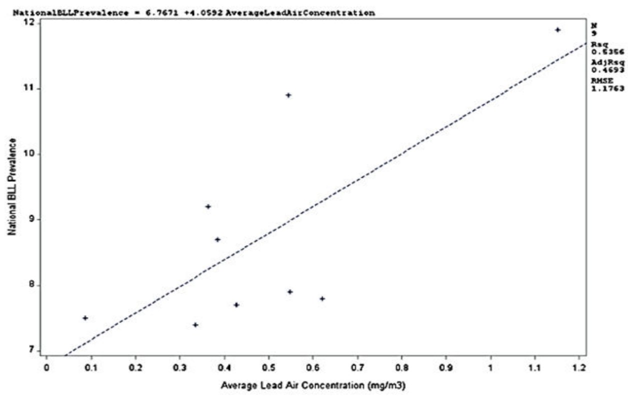

Figure 7: Linear Regression between mean air lead concentration and national BLL prevalence* from 2000-2008.

*Per 100,000 employed adults 16+ years old with BLLs ≥ 25 ug/dL.

DISCUSSION

We hypothesized that:

- There was a statistically significant decrease in the prevalence of high BLL between the years 2000 and 2009 for workers in the state of Utah and the U.S. as a whole.

- This decrease coincides with a decline in reported lead air concentration levels.

Our methodology and findings align with previous work on a lead exposure database built from a retrospective collection of 1,111 datasets from 175 published papers (lead data from area samples, personal measurements, and blood biomonitoring). Like this study, we compared national BLL and national air lead concentration to estimate trends over time and found that high BLL prevalence generally declined each year. Our study expands the knowledge base by comparing each data set from 2000-2009 to determine alignment to the 2010 healthy people goals.

Although Utah and the nation failed to meet the healthy people 2010 objective to reduce the number of employees occupationally exposed to lead with BLLs ≥ 25 µg/dL to 0 µg/dL, the U.S. did see a statistically significant overall decline in elevated BLL prevalence over the time frame. This decline is likely due to many different government regulations, including limits on lead within drinking water; banning of many lead containing objects, and institution of BLL surveillance programs. This decline also indicates that the healthy people 2010's goal was perhaps overly optimistic, especially given healthy people's 2020 occupational lead objective is much more modest, aiming to reduce by 10% the number of adult workers 16+ years older with BLLs ≥ 10 ug/dL. Similarly, while Utah failed to reach the healthy people 2010 goal, our findings indicate that Utah's high BLL prevalence decline was statistically significant. A larger dataset (*i.e.*, more years of data) may increase that significance even more. However, the model comparing Utah and the U.S. prevalence was much weaker, suggesting that the nation's BLL prevalence is a poor predictor of Utah's BLL prevalence. However, standardized state level guidelines from the Utah Lead coalition may soon bring Utah into line with national expectations and trends. Air monitoring remains the primary method to effectively predict extreme BLLs without biomonitoring. Every 1.0 mg/m^3 increase in lead air concentration corresponded to four additional cases per 100,000 employed adults with BLLs ≥ 5 ug/dL. However, caution should be employed when using this model for prediction, given the R^2 value of 0.54.

Several limitations may affect the generalizability of these results, including numerous types of bias from each of the collected datasets arising from the collection, storage, analysis, and reporting of samples. While the extent of this bias is unknown, the collection and analysis of blood lead and airborne lead are relatively simple and common procedures with written guidance. Data for the average lead air concentration could also be biased due to the various sampling methodologies. To avoid bias, most samples are collected on a random basis; however, the CEHD was collected by OSHA inspectors. These inspectors may perform random sampling when selecting which companies to investigate, but the OSHA officers are primarily concerned with compliance testing and compliant response. This sampling purpose involves selecting companies with worst case scenarios, which means the average air lead concentration may be biased towards an overestimate o f t he national me an exposure concentration.

The small sample size is another potential limitation. Only ten samples were extracted from the BLL prevalence datasets, one average for all the years between 2000-2009. While CEHD contains numerous data points, these were condensed into ten average air lead measurements for comparison to the other datasets. This limited number of samples reduced our statistical power; nonetheless, we observed a statistical decline between the two BLL prevalence datasets. The national BLL prevalence that has been referred to throughout this study is also not necessarily representative of the entire nation. Only about 25 states participated in ABLES at the start of 2000, and not all states that joined since 2000 have sent data every year. That being said, ABLES data continues to be the best source of BLL prevalence for the nation as most states send their BLL results to this database. Finally, although the primary lead exposure in this study is believed to be occupational, the measured BLL could also be from non-occupational sources such as gun use, recreational activities, residential lead paint, and environmental lead.

Future studies should consider focusing on socially and economically disadvantaged populations, as these groups are more likely to live in houses that used lead paint, live closer to lead emitting facilities and may not have received adequate information on lead containment. Several studies have advocated for identifying and tracking BLL throughout multiple high risk populations and educating them on the physical and mental harm, health assessments, and treatments. Vulnerable occupational populations, like refugees or immigrants, may be particularly at risk. Future studies can expand upon this knowledge and continue to look at various agents over different periods, such as past or current healthy people initiatives, different states, different agencies, and different databases and techniques.

CONCLUSION

Lead is a serious health concern that primarily affects occupational workers. By monitoring air lead concentration, and blood lead levels, employees can be alerted before chronic damage takes place. Using multiple datasets, we predicted that from 2000-2009 Utah and U.S. prevalence of individuals with ≥ 25 ug/dL BLL would decrease along with national air lead concentration to align with goals of healthy people 2010. Although Utah's and the nation's BLL high prevalence failed to reach desired levels, there was an overall prevalence decrease throughout the studied decade. Utah's prevalence levels were significantly lower than national ones but fell into patterns of peaks and declines. Air lead concentrations have mostly decreased as well, though all years were still found to be above the OEL. Every 1.0 mg/m^3 increase in lead air concentration corresponded to an estimated four additional cases per 100,000 employed adults with BLLs above 25 ug/dL. This alarming discovery is essential for future occupational health research and requires further investigation.

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