The Effect of the OSHA Lead Exposure in Construction Standard on Blood Lead Levels Among Iron Workers Employed in Bridge Rehabilitation

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Over 50,000 workers are at risk of occupational exposure to lead in the course of renovating the nation's deteriorating infrastructure. In mid-1993, to control exposure to lead in the construction setting OSHA promulgated a Lead in Construction Standard. In this study, we assessed the effect of the mandated changes in exposure conditions which followed the introduction of this new standard. We analyzed changes in baseline and maximum blood lead concentrations and in maximum increments in blood lead levels before and after introduction of the standard among iron workers employed in the renovation of a large, lead-painted, steel bridge in New York City. Results indicated that baseline and maximum blood lead levels fell significantly after the implementation of the provisions of the standard, as did maximum increments in blood lead concentrations. Seventy-six percent of the workers maintained blood lead concentrations below 20 µg/dl after the OSHA standard, as compared with 66% prior to its implementation. Increments of 20 µg/dl or more occurred considerably more frequently before introduction of the standard (13% before vs. 4% after; p = 0.01). Evidence of decreased exposure to lead was observed among iron workers who were present both before and after the introduction of the OSHA standard, as well as among iron workers newly hired after the OSHA provisions were put in place. These findings document the effectiveness of the OSHA construction lead standard in controlling exposure to lead in this complex and variable environment. The data indicate the utility of blood lead determinations in assessing the outcome of industrial hygiene interventions to reduce exposures to lead in the construction setting. Am. J. Ind. Med. 31:303–309, 1997. *© 1997 Wiley-Liss, Inc.*

KEY WORDS: lead exposure; biological monitoring; regulatory controls; construction industry

INTRODUCTION

Lead-based paint covers an estimated five billion square feet of nonresidential surface area in the United States, including some 89% of the nation's steel bridges. The nation's transportation infrastructure is badly in need of renovation and repair. Bridges have collapsed (e.g., the Mianus River Bridge in Connecticut) and other bridges are badly deteriorated. To remedy this situation, the U.S. Congress in 1991 passed the Intermodal Surface Transportation Efficiency Act (ISTEA), to fund infrastructure rehabilitation.

During the rehabilitation of bridges and elevated highways, more than 57,000 construction workers are potentially exposed to lead in the U.S. Nearly one million construction workers are exposed to lead overall [OSHA, 1993]. Until the promulgation of OSHA's Lead in Construction Standard

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[OSHA, 1993], these workers were not afforded the protective measures of OSHA's revised lead standard for General Industry [OSHA, 1978], even though the magnitude of lead exposure in the construction trades, particularly among structural steel rehabilitators and demolition workers, has been well documented [Zimmer, 1961; Campbell and Baird, 1977; Landrigan et al., 1982; Fischbein et al., 1984; Marino et al., 1989; MMWR, 1989, 1992, 1993]. The problem of lead poisoning in the construction trades has been reviewed recently [Osorio and Melius, 1995]. There are, however, few reports of the results of prospective biological monitoring among such workers, and only one study addresses the effectiveness of industrial hygiene interventions and utilizes biological indices of lead exposure in construction workers [Waller et al., 1994].

Biological monitoring may be an especially important tool when inhalation of a hazardous material is not the only significant route of exposure [Ashford et al., 1990], but where ingestion and/or cutaneous absorption may also be exposure paths. In the construction setting, opportunities for ingestion and subsequent absorption of lead through hand to mouth contact are common, and air monitoring may not offer sufficient information about either exposure to lead or approaches to its control. The recent OSHA standard for lead in construction is explicit about the importance of blood lead testing to identify workers at risk for adverse health consequences and to trigger medical removal policies and clinical assessment of individual workers. The standard, however, offers no discussion of the potential use of biological monitoring for lead in identifying the need for or evaluating the effectiveness of measures to reduce exposure to lead at the construction work site [OSHA, 1993].

In this report, we present the results of our evaluation of the extent to which the OSHA Lead Exposure in Construction Standard affected blood lead levels among iron workers employed on a bridge renovation project where there was extensive disturbance of lead-based paint.

BACKGROUND

From March 1993 until May 1996, we have been conducting an investigation of lead exposure to construction workers engaged in bridge rehabilitation and demolition. The goals of this study overall are four-fold: to develop an exposure assessment model for the construction trades, focused on lead, based upon the tasks performed by workers; to evaluate the role that biological monitoring for lead exposure can play in protecting workers and in exposure assessment; to assess engineering control technologies to reduce lead exposure; and to study the health effects of lead absorption in a population of workers whose work histories include high alternating with relatively lower exposures to lead, with intervening periods of varying lengths on jobs where there was no exposure to lead (e.g., new construction).

The site of the investigation is a steel bridge, constructed in 1908, which is 6,087 feet long, has two 1,600 foot long approaches entirely over land, and three suspended spans which rise 130 feet above water. During the 1993–1994 period, intensive ironwork was performed involving removal, refurbishment, and replacement of steel. Throughout the period of study, the content of the work tasks remained unchanged, as the underbridge repair platform moved down the length of the bridge. The work was performed largely by iron workers using pneumatic tools. A more detailed description of the work site and the nature of the renovation activities performed by the iron workers is presented by Goldberg et al. [1997].

Seventeen iron workers had been hired in November-December 1992 and were already present on the site at the time our investigation began in February 1993. These iron workers continued on this project into 1993, and an additional 88 iron workers were hired during calendar year 1993. By August-September 1993, 75 iron workers were employed on the bridge renovation site. Because inclement weather conditions prevented many rehabilitation activities during the winter months, bridge workers were laid off and the number of iron workers fell to 46 in January-February 1994. By April-May 1994, the number of iron workers rose again to 66 as the pace of renovation work increased. In all, a total of 201 different iron workers were employed on this project for varying periods of time through December 1994.

In May 1993, the OSHA Lead Exposure in Construction; Interim Final Rule (29CFR Part 1926), was released. In the latter part of 1993, in response to the promulgation of the OSHA standard, new approaches to the work were gradually introduced, changing exposure conditions on the work site. These changes included installing hot water sinks for hand washing; the development of a respirator program; distribution and replacement of coverall uniforms; training of workers in lead hazard recognition, in the health effects of lead, and exposure reduction; the establishment of separate facilities for eating and for changing/storing clothing; and the introduction of a "competent person" to monitor and improve exposure to lead among employees on the project.

Most of the contractor's efforts to comply with the provisions of the new interim standard were in place by December 1993. This afforded an opportunity to examine the effect of the introduction of control measures called for by the standard on workers' exposure to lead, since baseline and repeated follow-up blood lead data were available both before and after the introduction of these controls.

METHODS

Blood Lead Monitoring

Surveillance examinations, including the collection of blood specimens and the administration of interviews, were conducted in the contractor's office adjacent to the bridge. All individuals active at the site were recruited into the study and were examined at least once, including those with minimal opportunity for exposure, such as office workers and engineers who were office-based. Workers potentially exposed to lead were screened more frequently. As described above, work on the bridge began in November 1992, with a small crew of iron workers. From February 1993, when this study was initiated, until October 1993, workers were screened every two weeks. From November 1993 until December 1994, because the contractor wanted blood lead testing less frequently than biweekly, it was agreed that workers would be screened monthly. The protocol defining blood-lead monitoring frequency called for a baseline test for new employees before beginning work at the site or as soon as possible thereafter. Monitoring was conducted biweekly for all potentially exposed workers for at least two months. Thereafter, workers were monitored monthly if their blood lead levels remained below 25 μg/dl and if they did not increase by 5 μg/dl or more, regardless of the absolute blood lead level.

Each participant's lead absorption was assessed by obtaining a 7 cc blood sample from an arm vein. Samples were analyzed for total lead and free erythrocyte protoporphyrin by a laboratory accredited by the CDC (New York City Department of Health Bureau of Laboratories). Specimens were analyzed for blood lead concentration using atomic absorption spectrophotometry and for FEP using the Piomelli method [Piomelli, 1973].

A standardized interview was administered on-site at the time baseline blood samples were collected. Demographic data were collected on each participant's age, sex, race, educational level, and occupation. The questionnaire asked for information on the job prior to the present one, as well as potential for lead exposure at that job. Information was also collected regarding hobbies entailing potential lead exposure, smoking, present health status, and history of lead testing and absorption. Participants were also asked about previous health and safety training and current training needs, use of personal protective equipment, and other health and safety concerns they may have had.

At each subsequent blood test, brief follow-up questionnaires were administered to participants. The questionnaire inquired about job tasks and tools, locations, work crew members, work and hygiene practices, protective clothing, and job exposures since the time of the previous surveillance examination. Each questionnaire, including the baseline, elicited information on participants' symptoms.

TABLE I. Workers Employed on Bridge Rehabilitation Project, 1993–1994 Distribution by Trade

Occupation	Number	Percent
Iron workers	191	53
Painters	1	<1
Laborers	93	26
Carpenters	7	2
Electricians	6	2
Operating Engineers	7	2
Other	53	15
Total	358	100

STATISTICAL ANALYSIS

Univariate data are presented as frequency distributions, with means and standard deviations also specified for continuous measures. Blood lead parameters (e.g., baseline and maximum blood lead, maximum increase in blood lead, etc.) were classified into ordered categories prior to analysis. Comparisons of these parameters between calendar years 1993 and 1994 were made using the Mantel-Haenszel chi-square as a test for linear trend. Analysis of within-worker changes in blood lead parameters was performed using the paired t-test. Statistical significance was assessed at the 0.05 level.

RESULTS

Demographics

The distribution by trade of the overall work force under medical surveillance during the 1993–94 two-year period is presented in Table I.

At this site, the trade with the greatest risk for exposure to lead during bridge rehabilitation was the iron workers, since their tasks most frequently and routinely disturbed lead-based paint. Analysis of their blood lead levels was therefore judged to be most useful in assessing the effectiveness of the OSHA standard in controlling exposure. The distributions by sex, race, and time since beginning work in the trade for the iron workers under surveillance are presented in Table II.

The sex and race distributions of the iron workers are reflective of the overall prevalence of women and minorities in the skilled construction trades in the New

TABLE II. Iron workers Employed on Bridge Rehabilitation Project, 1993–1994 Distribution by Sex, Race and Years in the Trade

	Number	Percent
Sex		
Males	187	98
Females	4	2
Race		
White (non-Hispanic)	141	74
African American/Black	22	12
Hispanic	10	5
Native American	8	4
Other	10	5
Years in Trade*		
0–4	42	23
5–9	44	24
10–14	30	16
15–19	21	11
20–24	9	5
25+	40	21
Total	191	100

*Four subjects with missing data.

York metropolitan area (Table II). Native Americans, especially Mohawks, have a long tradition of employment in iron working throughout New York State.

As is evident from the distribution of time since beginning in the trade, the iron workers employed on this project were a relatively experienced group: 54% had worked at least 10 years as iron workers at the time they were hired, with a mean of 14.1 ± 10.9 years; 59% were at least 35 years of age.

The OSHA Standard and Blood Lead Levels

To examine the effect of the introduction of the OSHA standard on the results of blood lead monitoring, the maximum blood lead level for each ironworker in 1993 was compared with the maximum blood lead value for each ironworker in 1994 (Fig. 1). Levels were somewhat lower in 1994 ($p = 0.065$), with 76% remaining below 20 µg/dl as compared with 66% in 1993.

Iron workers newly hired onto the project had varying blood lead levels at baseline (Fig. 2), and a year-to-year difference in baseline levels was evident ($p = 0.03$). In 1993, 64% were hired with blood lead levels below 20 µg/dl, while 78% were below 20 µg/dl at baseline in 1994.

Because considerable variability and year-to-year trends in baseline blood lead levels were demonstrable, the maximum increment in blood lead level for each ironworker during employment on the bridge project was compared for

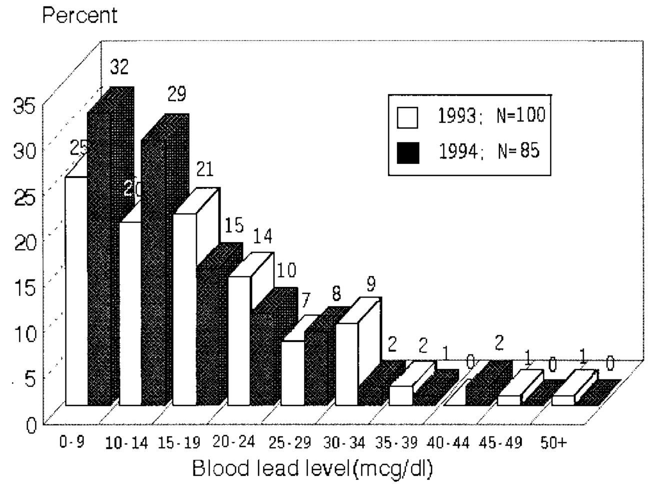

FIGURE 1. Maximum blood lead levels found in iron workers employed on a bridge rehabilitation project, 1993 vs. 1994.

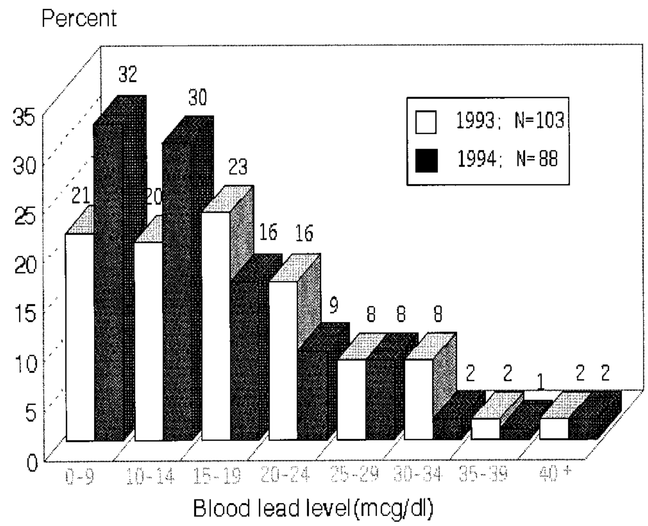

FIGURE 2. Baseline blood lead levels in iron workers hired onto a bridge rehabilitation project, 1993 vs. 1994.

1993 and 1994. The difference between each individual's minimum blood lead level and his/her maximum blood lead level which postdated the minimum was calculated for all iron workers in 1993. In similar fashion, a year-specific, maximum increment in blood lead level was calculated for all iron workers in 1994. The comparison of blood lead increments for the two years is presented in Figure 3 and shows a significant trend toward decreasing increments in blood lead levels in the second year ($p = 0.04$), after the introduction of the standard. In particular, increments of 20 µg/dl or more occurred considerably less frequently in the second year of monitoring (13% in 1993 vs. 4% in 1994; $p = 0.01$).

Because the group of iron workers included different individuals from year to year (possibly introducing variabil-

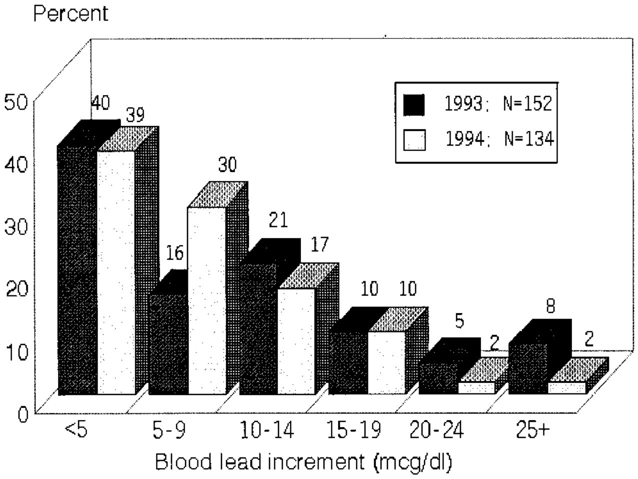

FIGURE 3. Year-specific, maximum increments in blood lead levels in iron workers employed on a bridge rehabilitation project, 1993 vs. 1994.

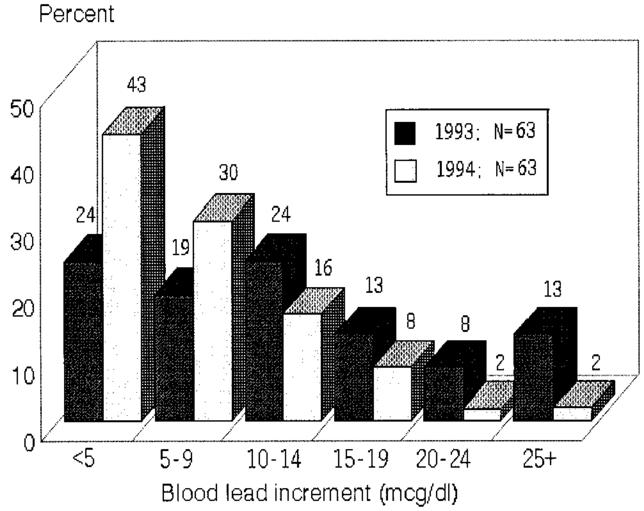

FIGURE 4. Year-specific, maximum increments in blood lead levels in 63 iron workers employed during both years on a bridge rehabilitation project, 1993 and 1994.

ity in work practices and personal hygiene behaviors which could affect lead absorption), a specific analysis of the year-to-year difference was performed for the 63 iron workers who were present on the job during both years. When the comparison of within-year increments in blood lead levels included only the 63 iron workers who were present on the job in both 1993 and 1994, a similar trend of significantly smaller increases in the second year is evident ($p = 0.0002$; Fig. 4). Only 4% experienced increments in blood lead level of 20 µg/dl or more in 1994, compared with 21% in 1993. Using the paired t-test, a statistically significant difference was found between the maximum increment in 1993 and the maximum increment in 1994 for each of the 63 iron workers (mean = -5.8 ± 9.2 µg/dl; $p < 0.001$).

To exclude any effect that learning to avoid exposure on this specific site might have had on iron workers' lead absorption over time, increments in blood lead levels among new hires during each year were compared (Fig. 5). While overall year-to-year differences were not statistically significant, increments in blood lead levels of 20 µg/dl or more were more common in 1993 than in 1994 (13% vs. 6%; $p = 0.09$), consistent with the results presented in Figures 4 and 5.

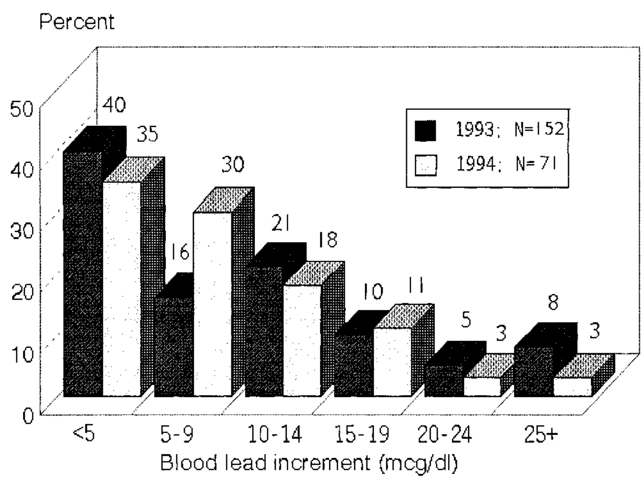

FIGURE 5. Maximum increments in blood lead levels in iron workers employed on a bridge rehabilitation project, new hires in 1993 vs. new hires in 1994.

DISCUSSION

The main findings of the study were that baseline and maximum blood lead levels among iron workers employed in structural steel rehabilitation, as well as maximum increments in blood lead concentrations, fell significantly after implementation of the provisions of the OSHA Lead in Construction Standard. The study provides evidence of the effectiveness of the OSHA standard and the usefulness of blood lead monitoring in assessing the outcome of industrial hygiene interventions.

The assessment of exposure and the effectiveness of controls used to reduce exposure to lead in the construction setting poses difficult challenges, given the extreme variability of the construction environment from location to location at any particular job site and over time. Biological monitoring can be an important tool to assess exposure and to guide interventions to reduce exposure if information about workers' recent tasks is available.

In the discussion of medical surveillance in the *Background* section of the OSHA standard document, reference was made to the particular relevance of medical monitoring in the case of lead exposure, "because, in the measurement of blood lead levels, there is a true indicator of health risk and, in the case of high blood lead levels, a course of action to address the risk,'' by which OSHA intends medical removal of the affected worker [OSHA, 1993].

Another valuable role for blood lead surveillance in the construction setting is in the assessment of the effectiveness of control measures introduced to reduce exposure. Because blood levels respond quickly to lead absorption, via the ingestion or inhalation route, monitoring this biological indicator of exposure usually represents an ''integrated'' index of total lead absorption via all routes within the prior 2–3 weeks. While blood lead testing cannot replace industrial hygiene assessment of the potential for lead exposure and the development of a worker protection plan, blood lead monitoring does offer a tool with which to evaluate the effectiveness of interventions such as the provisions of the OSHA standard.

The influence of the changes made in the conditions on this bridge rehabilitation site in response to the promulgation of the OSHA Lead in Construction Standard was measurable by comparing highest blood lead levels reached, as well as maximum increments in blood lead experienced by iron workers on this rehabilitation project, before and after the provisions of the standard were implemented. The work tasks and the condition of the leaded paint on which the work was done were essentially unchanged during the period of the study, since the tasks (removal of old steel, replacement with new steel) were performed in repeated succession by iron workers located on an underbridge platform that moved down the length of the bridge structure as the renovation of each section was completed.

The year-to-year comparisons indicate that OSHA-mandated approaches to exposure reduction were effective in better controlling lead absorption among those most heavily and regularly exposed and were particularly useful in controlling the exposures giving rise to the greatest increases in blood lead levels among iron workers. That the standard may have had more general effect on other job sites as well is suggested by the lower baseline blood lead levels found among new hires in 1994 vs. those newly hired in 1993.

It should be noted that blood lead testing was performed on a biweekly basis during the first seven months of the project and monthly thereafter. This is likely to have narrowed the differences in blood lead levels and increments observed between 1993 and 1994, since test-to-test increases in blood lead levels for individual workers prompted interventions by industrial hygienists to reduce exposure. This greater testing frequency tended to decrease the magnitude of excursions in blood lead levels in the first year of the study.

Waller et al. [1994] examined the effect of workplace modifications approximating the requirements of OSHA's Lead in Construction Standard on blood lead and ZPP levels among 18 iron workers and laborers employed in the demolition of a lead-painted steel tank. The data indicated a protective effect of the work site modifications against lead absorption. The study, the first to address the effect of the new standard, was limited by the few workers present both before and after the change in conditions, and the unavailability of baseline blood lead results for the period before the intervention. Nevertheless, enforcement of the provisions of the OSHA Lead in Construction Standard appeared to offer protection against lead exposure among members of a stable work force on a long-term project.

The value of blood lead monitoring as an indicator of the adequacy of controls against exposure raises questions regarding the frequency of retesting called for in the OSHA standard. The marked variability of conditions at different locations on the same project and during different phases of rehabilitation work suggests that repeat testing only after a period of two months has elapsed since baseline assessment will miss opportunities to identify exposures in sufficiently timely fashion to permit industrial hygiene investigations and intervention. More frequent blood lead determinations, early in the life of a rehabilitation project and when exposure conditions have altered due to changes in task or setting, may prevent lead toxicity among such workers and avoid the necessity for worker removal and the consequent disruption of structural rehabilitation activities.

In the current study, it was not possible to identify which of the several improvements in exposure control were most influential in reducing blood lead levels, largely because a number of possibly contributory factors were modified in the same period of time. The enhancement of the respirator program at the site, the introduction of hand washing facilities, the removal of paint by chemical stripping before torch use, the availability on-site of a union-trained ''competent person,'' and both formal and informal education/training regarding lead hazards in structural steel rehabilitation work were all phased in gradually in the late summer and early fall of 1993. Other than the use of chemical strippers, few engineering controls were employed in the reduction of exposure on this project. The presence of ''outside'' public health observers (the investigators and support staff) is likely to have played a role in improving exposure conditions at the site. Despite the difficulty in identifying the most influential factors, it is clear from the blood lead monitoring data that exposure conditions on this site did improve as a consequence of the implementation of the provisions of the OSHA standard. The results obtained when the maximum increments in blood lead levels were compared for newly hired iron workers in each of the study years suggest that the differences evident in Figures 4 and 5 may not have been solely the result of ironworker's learning ways to avoid exposure as their tenure on the job continued but, in fact, reflected better control of exposures in this complex and variable environment.

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