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Background: While regulations for workplace lead exposure become more strict, their effectiveness in decreasing blood lead concentrations and the method by which this is attained have not been evaluated.

Methods: An analysis was conducted of 10,190 blood lead samples from employees of 10 high-risk workplaces collected in Manitoba, 1979–1987, as part of regulated occupational surveillance.

Results: A significant decrease in blood lead concentrations was observed overall as well as for each individual company. A 1979 governmental regulation to reduce lead to below 3.38 μmol/L (70 μg/dl) was followed by a drop in blood lead concentrations; a 1983 order to reduce blood leads to below 2.90 μmol/L (60 μg/dl) was not followed by such a drop. Longitudinal analysis by individual workers suggested that companies were complying by use of administrative control, i.e., removing workers to lower lead areas until blood lead levels had fallen, then returning them to high lead areas.

Conclusion: Focusing upon blood lead as the sole criterion for compliance is not effective; regulations must specifically require environmental monitoring and controls. Biological surveillance serves as "back-up" to environmental surveillance and this database illustrates the usefulness of a comprehensive centralized surveillance system. (Am J Public Health. 1991;81:736–740)

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veillance reported from 10 high-risk workplaces. Five workplaces had regular medical monitoring programs throughout the period 1979–87 inclusive, and five conducted comprehensive and continuous programs for at least two years during this period. In other workplaces the medical monitoring was sporadic and voluntary. All blood lead analyses were conducted at the provincial government’s Technical Services Laboratory located in Winnipeg, Manitoba. The laboratory is accredited by the American Industrial Hygiene Association and participates in the Blood Lead Proficiency Testing program of the Centers for Disease Control in Atlanta, as well as the program conducted by the Centre de Toxicologie in Quebec. Blood leads are analyzed using the Fernandez Method.4

Those whose blood lead concentrations exceeded 2.41 µmol/L (50 µg/dl) on at least one occasion, had an annual frequency of testing ranging from one to 21, median of four and mode of four, whereas those whose blood lead concentrations were always less than 1.93 µmol/L (40 µg/dl) had an average annual testing frequency ranging from one to nine, with median of one and mode of one. To adjust for this variation, a quarterly median was taken for each individual. If an individual had only one blood lead test in a given year, the same result was entered in all four quarters for that year. If an individual had blood tests monthly, only the median of each quarter was entered for analysis.

As measures of blood lead concentrations tend to be skewed, most of the analyses were smoothed (using a median quarterly or annually as the case may be) and the overall medians analyzed. Contingency table analysis allowed the comparison of aggregated distributions of blood lead concentrations, while linear regression analysis assessed company trends over the nine-year period, and Mantel-Haenszel trend tests evaluated specific target proportions over shorter time segments (i.e. proportion of values over 70 µg/dl during the three years following 1979 and proportion over 60 µg/dl in the three years following 1983).

To gain insight into the mechanism underlying the longitudinal variations of individual blood lead concentrations, first order auto correlations to assess the influence of one result on the next among individual workers and testing the run of signs of first differences for randomness to assess individual patterns were performed.5 6 The overall effect of administrative controls as hypothesized by a negative association between last blood lead concentration nearing the target level and current blood concentrations was tested using the Mantel-Haenszel chi-square stratified by regulatory period.

Industrial hygiene observations and measurements were gleaned from the records of the provincial government’s workplace safety and health inspectorate.

Occupational Lead Exposure and Regulatory Process

Workplace safety and health is a provincial responsibility in Canada, with each province enacting its own legislation and regulations. The Workplace Safety and Health Act in Manitoba, proclaimed in 1977, empowers the minister to issue an order requiring an occupational health service at designated workplaces, with penalty of fine for noncompliance. This permitted the minister in charge of occupational health for the province to issue an order to five companies in 1979 to reduce blood lead concentrations to below 3.86 µmol/L, (80 µg/dl). There was no mention of environmental monitoring in the order. An individual was to be removed from the plant when his blood lead concentration exceeded 3.86 µmol/L or transferred to a low lead exposure area when the blood lead ranged from 3.38–3.86 µmol/L (70–80 µg/dl). In 1983, after considerable debate, the 1979 order was revised reducing the blood concentration removal level to 3.35 µmol/L (70 µg/dl), with workers to be transferred to low lead areas when the blood concentration ranged from 2.90–3.38 µmol/L (60–70 µg/dl). There was no mention of differential levels for women, or of environmental monitoring.

The five firms that received this order consisted of one battery manufacturer, two primary lead–using industries, one secondary lead smelter, and one combined battery breaking/secondary smelter operation. These companies all operated continuously from 1979 to 1987 with the exception of the combined battery breaking/secondary smelter operation which was shut down briefly for economic reasons during 1983. Three other companies conducted biological monitoring over part of the same period; a primary copper smelter with additional production of zinc and lead concentrate (1982–87), a battery breaking operation in a reclamation yard (1985–87), and an aluminum forging operation (1985–86) with incidental lead exposure.

In 1986 following years of controversy and no written policy, the Workers’ Compensation Board (WCB) in Manitoba essentially established a blood lead concentration of 2.41 µmol/L (50 µg/dl) as a compensable level.7 Thirty-three claims for lead poisoning had been allowed by the Manitoba WCB prior to 1986; 54 were allowed in the two years following this policy statement.

Results

Table 1 contains the 10,190 blood lead concentrations of employees who worked in the 10 designated plants between 1979 and 1987 inclusive. The proportion of values over 3.86 µmol/L (80 µg/dl) has steadily decreased; there is a statistically significant difference in the distribution of lead concentrations over the years, (p < .0001). There were no essential changes in this distribution when one entry per quarter for each worker is included regardless of the number of tests performed on that worker during that particular year (data available from author on request). Figure 1 illustrates the trends in median blood lead concentrations over time in each of the five companies that operated throughout this period (with the exception of a brief plant closure in 1983 in one). Median blood lead levels by year and type of plant are given in the Appendix.

A separate analysis was conducted to assess the proportion of blood lead concentrations over 3.38 µmol/L (70 µg/dl) in the three years following the 1979 order which required a reduction to below this level. Both the overall trend as well as the trend within each of the five firms subject to this order showed a highly significant decrease in the proportion of blood leads over this level (overall from 7.9 percent in 1979 to 0.8 percent in 1982). When a similar assessment was done for the 1983 order, only one of the then six companies showed a statistically significant decrease in proportion of blood leads over 2.90 µmol/L (60 µg/dl), the new target level (data available from author on request). Two companies, a secondary smelter and a combined battery breaking/secondary smelter operation, which had 11.2 percent and 11.8 percent of blood levels over 2.90 µmol/L (60 µg/dl), respectively, at the time of the 1983 order, had 13.9 percent and 16.9 percent over 2.90 µmol/L (60 µg/dl), respectively, three years later.

Industrial hygiene investigation revealed that after the first government intervention, some hygiene and/or engineering controls were implemented in all of the firms in question with each firm adopting a unique strategy depending on its condi-

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tion. Thereafter, companies seemed to be making greater use of administrative controls, i.e. removing workers to lower lead-in-air areas when blood lead concentrations approached the action level, only to return them to the higher areas after their blood lead concentration had fallen. Industrial hygiene inspections found for example, that while the lead-in-air levels had dropped from 300 μg/M³ to less than 150 μg/M³ in a primary lead using company, between 1979 and 1983, such a decrease was not observed in the inspection of a secondary lead smelter where environmental levels continued to exceed 300 μg/m³. A second secondary smelter demonstrated a reduction of near 150 μg/m³ on average but some areas, notably the furnace area, demonstrated no substantial reduction in air-borne lead with concentrations approaching 400 μg/m³ and personal protection being used as a protective strategy. No ongoing environmental or personal monitoring programs were in place and government monitoring was generally complaint-based. Environmental data are thus incomplete.

To further investigate the apparent failure of the 1983 order to produce a continuing decrease in blood lead concentrations, longitudinal analysis was performed for all workers who ever had values of 2.90 μmol/L (60 μg/dl) or greater. A graph for these workers individually showed a marked “titration” pattern, indicating use of administrative controls. Figure 2 shows two typical examples of this pattern. It demonstrates that as a worker’s blood lead concentration approaches the action levels he is removed to a lower lead area, and after his blood lead concentration falls, he is probably returned to a higher lead-in-air concentration since his blood lead level rises. This titration pattern in individual workers was present throughout the period of data collection. Its existence was further demonstrated by the significant (p = 0.0001) finding that if a worker’s blood lead was less than 2.41 μmol/L (50 μg/dl) his next blood lead would be higher and vice versa. This indicates that an overall decrease in lead exposure in the plant was not occurring because the lead exposure was being averaged over a pool of employees. Four of the eight companies still in operation in 1985 had 18–50 percent of blood lead concentrations over 2.90 μmol/L (60 μg/dl); one other company brought its percentage down to 1.9 percent, while the remaining three companies had had less than 1 percent even prior to the 1983 order. The workforce turnover rates were higher in the four companies with poor compliance than in the four with lower proportion of concentrations over 2.90 μmol/L (60 μg/dl) (data available from author on request). There was much less evidence of titration in the four with better compliance (data available from author on request).

Discussion

The prevention of lead poisoning requires: 1) knowledge of dose response relationships with establishment of an acceptable target blood lead “threshold” to reduce the potential for subclinical lead toxicity, 2) effective surveillance of the environment and of the at-risk population, and 3) action to reduce lead exposure at the source. Considerable knowledge exists with respect to “threshold” levels of exposure for different adverse effects, as summarized elsewhere. There is a need to intensify the monitoring of lead levels in the at-risk population in order to take action which would result in a safer workplace. Methods used to monitor trends of occupational illness and injury are usu-
ally developed primarily for other purposes, making them less useful for occupational health surveillance. Most states have reporting systems specifically for occupational disease, but the completeness of reporting is rarely satisfactory due to a lack of effective centralized monitoring, and disincentives for physicians and others to report occupational disease.

One of the main purposes of surveillance systems is to evaluate the effectiveness of worksite control programs. However, there is little information addressing the effectiveness of government regulatory strategy in controlling work-related illness and injury, and there has certainly been controversy in this regard. This study illustrates an overall decrease in the extent of lead poisoning over the last decade. However, on careful examination it is apparent that while the 1979 government order to reduce blood lead concentrations to below 3.38 μmol/L (70 μg/dl) was effective, the 1983 order to reduce blood leads to below 2.90 μmol/L (60 μg/dl) was less so. Thus the conclusion regarding the effectiveness of Manitoba’s regulatory strategy is mixed.

Our findings show that when biological monitoring is the only criterion for compliance, utilization of administrative controls enables companies to comply with stricter regulations without decreasing overall lead exposure. The practice of administrative controls is problematic for several reasons. It results in subjecting more people to lead exposure, thereby failing to reduce overall lead exposure; it often causes employment disruption with its consequent socioeconomic consequences; it usually fails to reduce individual body burden of lead. The oscillations observed below the action level (Figure 2) do not represent lead exposure followed by lead excretion. Rather, due to man’s relative inability to excrete lead, the downstrokes represent lead storage within the body. The end result of this process is chronic lead poisoning. This finding is supported by the clinical observations of the clinician authors (AY and MT) in which modest blood lead elevations in several long-term employees have been noted to be accompanied by marked increases in erythrocyte protoporphyrin concentrations.

In 1987 the minister responsible for occupational health in Manitoba issued a further order requiring “...a worker to be removed from the lead containing environment until his/her lead level returns to acceptable levels below 2.41 μmol/L (50 μg/dl). The worker may work in a job with minimal lead exposure (30 μg/M3) considered as an 8 hour average ...” Moreover, the order stated that the exposure to the worker shall be “no greater than 50 μg/M3.” Only upon a detailed engineering assessment by a qualified engineer can consideration be given to permit exposure levels...to exceed 50 μg/M3.” As most Canadian jurisdictions utilize the American Conference of Governmental Industrial Hygienist (ACGIH) level of 150 μg/M3, this order was considered quite progressive by some and draconian by others. Regardless of the appropriateness of the lead-in-air concentration chosen, the data presented here demonstrate that the inclusion of an environmental target level was a needed addition. Nonetheless, biological monitoring must continue, with the data base described above serving an important role in monitoring the effectiveness of this new regulation.

In conclusion, while appreciation of lead as a subclinical toxin is essential, and a comprehensive blood lead surveillance system for high risk industries is crucial, unless biological monitoring is in conjunction with environment monitoring and measures to decrease exposure at the source, the overall goal of reducing occupational lead poisoning will not be achieved.

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References


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**APPENDIX—Median Blood Lead vs Year for Lead Exposed Workers from Five Manitoba Companies**

<table>
<thead>
<tr>
<th>Firm</th>
<th>1979-82</th>
<th>1983-87</th>
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<td></td>
<td>Observations</td>
<td>P values</td>
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<tr>
<td></td>
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<td>Range</td>
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<tr>
<td>⊳ = Combined battery</td>
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<tr>
<td>breaking and secondary</td>
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<td>140–212</td>
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<tr>
<td>◻ = Primary lead user</td>
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<td>504–860</td>
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* Trend Test for Proportions >70 μg/dl
* Trend Test for Proportions >60 μg/dl
* Data unavailable for 1983 due to plant closure