Blood Lead Levels Among Children of Lead-Exposed Workers: A Meta-Analysis

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Background *To further assess the utility of targeted blood lead screening for children from households with members having occupational lead exposures, we conducted a meta-analysis of all available reports of take-home lead exposures. Our objective was to estimate the blood lead levels among U.S. children (ages 1–5) from households with lead-exposed workers.*

Methods *Reports considered for inclusion were cited in Medline, Toxline, Excerpta Medica, and Bio-Med plus all unpublished reports available at the National Institute for Occupational Safety and Health through 1994. The a priori criteria for inclusion of U.S. reports required their having data on: (1) venous blood lead levels for children, (2) children's ages, (3) data for at least five children, (4) workers' occupations, (5) workers' blood lead levels, and (6) data collection methods.*

Results *Based on a meta-analysis of 10 reports from 1987 through 1994, the children (n = 139) of lead-exposed workers (n = 222) had a geometric mean blood lead level of 9.3 μg/dL compared to a U.S. population geometric mean of 3.6 μg/dL (P = 0.0006). Also in this group, 52% of the children had blood lead levels (BLLs) ≥ 10 μg/dL compared to 8.9% in the U.S. (P = .0010), and 21% of the children had BLLs ≥ 20 μg/dL compared to 1.1% in the U.S. (P = .0258).*

Conclusions: *We estimate, based on 1981–83 survey data, that there are about 48,000 families with children under six living with household members occupationally exposed to lead. If the findings from this meta-analysis (admittedly limited by small numbers) are generalizable, about half of the young children in these families may have BLLs ≥ 10 μg/dL. Data were too sparse to determine if children of workers with elevated blood leads were at greater risk than children whose parents were only known to be lead exposed. Our findings support the position that children of lead-exposed workers should be targeted for blood lead screening.* Am. J. Ind. Med. 36:475–481, 1999. *Published 1999 Wiley-Liss, Inc.*†

KEY WORDS: take-home toxins; take-home lead; children; paraoccupational exposure; parents occupational lead exposure; meta-analysis; children's blood lead screening

INTRODUCTION

Lead exposure and lead levels for U.S. children have decreased over the last two decades due mainly to efforts to eliminate lead from gasoline and soldered food cans. From 1976 to 1994, the geometric mean of BLLs for children aged 1–5 years decreased from 15.0 μg/dL to 2.7 μg/dL [Pirkle et al., 1998]. Nonetheless, in 1994, 4.4% of children aged 1–5 years still had BLLs ≥ 10 μg/dL, the action level

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recommended by the Centers for Disease Control and Prevention (CDC) [CDC, 1997]. For the entire U.S. population, this percentage translates into about 890,000 children aged 1–5 years.

In accordance with CDC guidance, state health officials in collaboration with childhood health-care providers, representatives from local health departments, managed care organizations, physicians, parents and others may determine whether childhood lead screening will be universal, limited to children living in older housing and high risk communities, or targeted to children in all high risk groups. The CDC has long recognized that parental occupation in a lead-exposed industry is a potential source of take-home lead exposure for children. Questions about parental occupation are recommended as additions to the personal-risk questionnaire to determine whether targeted screening should be conducted [CDC, 1997].

CDC's National Institute for Occupational Safety and Health (NIOSH) has been charged with the responsibility to study the contamination at workers' homes [US Department of Health and Human Services, 1995]. As part of this NIOSH effort, a study of elevated BLLs among the children of construction workers [Whelan et al., 1997] found that 26% of the workers' children had BLLs equal to or more than CDC action level of 10 μg/dL, and a companion study [Piacitelli et al., 1997] found that construction workers' occupational exposures were the primary cause of lead contamination found in their cars and homes. To further assess the utility of targeted-screening for the children of lead-exposed workers, we now report on a meta-analysis conducted to estimate the extent of child lead poisoning from occupational sources.

MATERIALS AND METHODS

Data Sources

We identified relevant published reports by searching Medline, Toxline, Excerpta Medica, and Bio-Med (French) by using the key words: take-home lead, children, paraoccupational exposure, and parents' occupational lead exposure. Unpublished reports came from the files of NIOSH's Adult Blood Lead Epidemiology and Surveillance (ABLES) program [CDC, 1995] and include surveys conducted by NIOSH staff and reports from state-based surveillance programs.

Study Selection

For the meta-analysis, we selected published and unpublished U.S. reports through 1994 which contained the following: (1) venous blood lead levels (BLLs) for the children, (2) ages for the children, (3) data for at least five children, (4) information on the workers' occupations, (5) BLLs for the workers, and (6) information on the methods used to collect the data. Only 10 reports, 5 published and 5 unpublished, met the inclusion criteria.

Aggregation for Meta-analysis

The 10 reports selected for meta-analysis were grouped into two types: (1) "exposed", where the authors first identified workers found to have elevated blood lead levels and later collected data on their occupation and their children's BLLs, and (2) "potentially exposed", where the authors collected the BLLs of the children of lead-exposed workers without prior knowledge whether the workers had elevated BLLs. Data on 139 children and 222 workers in six industries were identified.

Comparison Population

Blood lead data for 2,234 children aged 1–5 years collected between 1988 and 1991 were drawn from the National Health and Nutrition Examination Survey (NHANES III) [Brody et al., 1994 and Pirkle et al., 1994] and used for comparison. The 10 reports included in this meta-analysis were written or published between 1987 and 1994.

Data Synthesis

Authors of the original reports were contacted to obtain individual BLLs for all children. These data were determined to be approximately log-normally distributed. All of the worker data was assumed to be log-normally distributed, and the data were log transformed for further analysis. Geometric means and confidence intervals for worker BLLs were reported. For the three studies in which individual worker data were not given, only the minimum and maximum BLLs were available. Thus, the standard deviation was estimated by using the range [Pearson, 1932] in the log scale, and the geometric mean was taken as the exponentiation of the average of the log transformed minimum and maximum values.

Exact confidence intervals for the children's proportions in the individual reports were obtained by using LogXact [LogXact-Turbo, 1993]. Geometric means and confidence intervals (95% CI) were obtained for each report by using standard parametric methods. The confidence interval for the NHANES III data was obtained from its Phase 1 report [Brody et al., 1994]. Hypothesis tests comparing individual report geometric means for children to the geometric mean for NHANES III were obtained by using the t' test statistic (appropriate when variances are unequal) on the log transformed scale [Dowdy and Wearden, 1983]; the degrees of freedom was the number of children in the individual study minus one. This modification was necessary because NHANES III is not a simple random sample. Tests for comparing individual study proportions (binomial based) to NHANES III (normal based) were not performed because the sample sizes were too small for a large sample test, and no small sample test was available for this combination of simple and complex random samples.

Meta-analytic Statistics

When groups of reports were treated as random samples from a larger set of reports, means (of log transformed data) and proportions were treated identically with respect to estimates and confidence intervals. The overall mean or overall proportion was estimated as the sum of report means or proportions weighted by corresponding sample size.

$$\left(w_i = \frac{n_i}{\sum_{j=1}^{k} n_j} \right).$$

The variance of this estimate was calculated by

$$\sum_{i=1}^{k} \frac{w_i (Y_i - \bar{Y})^2}{k - 1},$$

where k is the number of reports. This is analogous to Cochran's result for equal sample sizes [Cochran, 1977]. Confidence intervals were then obtained by standard parametric methods, using the number of reports, k, as the sample size. For each group of reports concerning children, the t' test mentioned above was used to compare the group means and proportions with NHANES III. Here, the degrees of freedom was the number of reports in the meta-analysis minus 1.

RESULTS

Literature Search

The search for reports on take-home lead in published and unpublished sources, found 51 from the U.S. Of the 51

TABLE I. Chronologic List of U.S. Reports Included in Meta-Analysis

Authors (Type of Report)	Industry	Location	Publication	Rationale for Selection of Children
Kaye et al., 1987; CDC, 1985; Novotny et al., 1985 (Exposed)	Ceramics–capacitor and resistor manufacturing	Colorado	Arch Environ Hlth, MMWR, unpublished	Lead poisoned workers' children
Lussenhop et al., 1989 (Potentially exposed)	Radiator repair	Minnesota	Am J Pub Hlth	Survey of radiator repair workers' children
Pichette et al., 1989 (Potentially exposed)	Battery–manufacturing and recycling	Texas	Unpublished	Survey of battery workers' children
Nunez et al., 1993 (Potentially exposed)	Radiator repair	New York	Am J Ind Med	Survey of radiator repair workers' children
Keyvan, 1993 (Exposed)	Construction—3 painters, 1 sandblaster, 1 lead burner, 1 pipe fitter, 2 unspecified (lead-related)	Maryland	Unpublished	Lead poisoned workers' children
Staes, 1995 (Potentially exposed)	Firing range—(F.B.I.) instructors, gunsmiths and technicians	Washington DC	Unpublished	Survey of firearms instructors' children
Gittleman et al., 1994; CDC, 1992; NIOSH, 1991 (Exposed)	Battery reclamation	Alabama	J Occup Med, MMWR NIOSH	Lead poisoned workers' children
Czachur et al., 1994 & 1995 (Exposed)	Construction—8 construction workers, 1 battery worker	New Jersey	Unpublished, Am J Ind Med (1995)	Parent BLL $\geq$ 40 µg/dL
Illinois, 1994 (Exposed)	Laborers—3 laborers, 1 assembler, 1 machinist, 1 furnace operator, 1 police, 1 fire, 2 unknown	Illinois	Unpublished	Parent BLL $\geq$ 25 µg/dL
Rabin, 1994 (Exposed)	Construction—4 painters, 1 glassblower, 1 forklift operator, 1 compounder, 1 deleader	Massachusetts	Unpublished	Parent BLL $\geq$ 25 µg/dL

TABLE II. Meta-Analysis of Blood Lead Levels for Children Aged 1–5 Years Reported in 10 Reports Compared to NHANES III by Individual Report, Type of Report and Combined. Data for Workers from the 10 Reports (Right Hand Column)

Citation	No. of Children[a]	Geometric mean BLL in μg/dL (95% CI)	P value versus NHANES[b]	Percent BLLs ≥ 10 μg/dL (95% CI)[c]	P value versus NHANES[b]	Workers—Geometric Mean BLL μg/dL (95% CI), Number of Workers, Workers linked to children or not[a]
Lussenhop et al., 1989	16	8.6 (7.0–10.6)	< .0001*	38% (15–64)[c]		17.0 (14.6–19.8)[d] n = 52 not linked
Pichette et al., 1989	41	13.3 (10.6–16.8)	< .0001*	64% (60-88)[c]		28.8 (25.6–32.4) n = 40 linked
Nunez et al., 1993	7	9.1 (5.8–14.4)	.0029*	43% (10–82)[c]		34.8 (24.9–48.6) n = 7 linked
Staes, 1995	9	Embargoed[g]		Embargoed[g]		Embargoed[g] n = 33 not linked
Meta-Analysis (Potentially exposed)	73	9.4[e] (3.3–26.6)[f]	.0627	55%[e] (6–100)[f]	.0579	16.7[e] (6.1–45.5)[f]
Kaye et al., 1987	20	12.1 (9.7–15.2)	< .0001*	75% (51–91)[c]		46.5 (39.8–54.3)[d] n = 41 not linked
Keyvan, 1993	9	6.6 (3.3–13.3)	.0866	44% (14–79)[c]		41.3 (30.8–55.4) n = 8 linked
Gittleman et al., 1994	6	32.6 (25.3–41.9)	< .0001*	100% (61–100)[c]		66.9 (61.4–72.8)[d] n = 14 not linked
Czachur et al., 1994	13	7.3 (4.7–11.3)	.0053*	31% (9–61)[c]		46.1 (36.4–58.4) n = 9 linked
Illinois, 1994	10	7.1 (3.4–14.7)	.0669	30% (7–65)[c]		29.5 (26.4–33.1) n = 10 linked
Rabin, 1994	8	5.7 (3.1-10.4)	.1265	12% (0–53)[c]		38.0 (29.0–49.8) n = 8 linked
Meta-Analysis (Exposed)	66	9.3[e] (5.3–16.2)[f]	.0078*	50%[e] (19–81)[f]	.0199*	45.4[e] (35.3–58.4)[f]
Meta-Analysis (All reports)	139	9.3 (6.3–13.9)[f]	.0006*	52% (32–73)[f]	.0010*	25.1 (15.2–41.2)[f]

*Significantly different from NHANES III mean or proportion
[a]The number of children and workers might be different from published data. We eliminated data for children < 1 or > 5 years old and, where workers were linked to children, we eliminated data for workers not linked to children.
[b]NHANES III: 2,234 Children 1–5, geometric mean BLL = 3.6 μg/dL (95% CI 3.4–4.0); BLLs ≥ 10 g/dL = 8.9% (95% CI 5.2–12.6)
[c]Exact confidence interval for a binomial proportion for individual reports.
[d]Geometric means and confidence intervals are estimates derived from published ranges of data.
[e]T-test for difference in potentially exposed vs. exposed reports: children's means ($P =$ 09783), children's proportions ($P =$ .8118), worker means ($P =$ .0162).
[f]Confidence intervals calculated using modified Cochran method.
[g]These results are embargoed until publication.

take-home reports, 16 were on battery workers, 8 on radiator repair workers, 7 on construction workers, 4 each on smelter workers and manufacturers, 3 each on pottery and ceramics workers, and 1 or 2 on workers associated with a variety of other industries and occupations.

Reports Selected for Meta-Analysis

Ten individual U.S. reports met all six of the inclusion criteria and were selected for the meta-analysis. These reports (including 14 references) are listed in Table I. Thirty-seven U.S. reports were excluded from the meta-analysis for the following reasons: 17 reported on less than five children, 13 did not present children's blood lead data, and 7 did not give the children's ages.

Individual and Overall Meta-Analytic Statistics

The mean BLLs and proportions for children aged 1–5 years are presented in Table II for each of the 10 reports. These results are provided along with the meta-analytic results aggregated by report type and overall. The *P* values for comparisons to NHANES III data for children aged 1–5 years are also provided.

The individual findings for the adult workers in the 10 reports, as well as the meta-analytic findings by report type and overall, are also included in the right-most column of Table II. In four reports, the workers were not ‘‘linked’’ to the children; correlations were not tested. In six reports the workers were ‘‘linked’’ to the children but there were no significant correlations between the children's and workers' BLL data.

For the children's data (n = 139), the geometric mean BLL was 9.3 μg/dL, which was significantly greater than the NHANES III geometric mean of 3.6 μg/dL ($P = .0006$). The overall proportion of BLLs greater than 10 μg/dL for the children was 52% (95% CI 32–73%), which was also significantly greater than the NHANES III value of 8.9% ($P = .0010$). Similar results were found whether the parents were known, a priori, to have an elevated BLL or merely to have lead exposure.

TABLE III. Meta-Analysis of Blood Lead Levels for Children Aged 1–5 Years Reported in 10 U.S. Reports by Publication Status, Calendar Period and Industry

Report Aggregation Factor (no. reports /no. children)	Geometric Mean BLL in μg/dL (95% CI)	*P* value [a] versus NHANES	%BLLs ≥ 10 μg/dL (95% CI)	*P* value [a] versus NHANES
Publication Status				
Published[b] (5/62)	10.6 (6.0–18.9)	.0070*	55% (22–87)	.0178*
Unpublished[b] (5/77)	8.4 (3.7–20.0)	.0459*	51% (10–91)	.0464*
Calendar Period				
1985–1989[c] (3/77)	11.9 (7.1–19.9)	.0116*	68% (21–100)	.0337*
1990–1994[c] (7/62)	6.9 (3.6–13.3)	.0528	34% (8–60)	.0604
Industry				
Battery[d] (2/47)	14.9 (0.3–65.8)	.1330	79% (0–100)	.0761
Ceramics[e] (1/20)	12.1[e]	[e]	45%[e]	[e]
Radiator[d] (2/23)	8.8 (6.2–12.4)	.0402*	39% (8–70)	.0666
Laborers[e] (1/10)	7.1[e]	[e]	30%[e]	[e]
Construction[d] (3/30)	6.6 (4.8–9.1)	.0201*	30% (0–53)	.1370
Firing Range[e] (1/9)	Embargoed[f]	[e]	Embargoed[f]	[e]

*Significantly different from NHANES III mean or proportion
[a]NHANES III: 2,234 Children 1–5, mean BLL = 3.6 μg/dL (95% CI 3.4–4.0); BLLs ≥ 10 μg/dL = 8.9% (95% CI 5.2–12.6)
[b] T-test for difference in reports by publication status: means ($P = .5303$), proportions ($P = .8284$).
[c] T-test for difference in reports by calendar period: means ($P = .1029$), proportions ($P = .0625$).
[d] T-test for difference in reports by industry: means ($P = .1095$), proportions ($P = .1611$), (joint Bonferroni test).
[e] Variability could not be estimated for industries with only one report.
[f] These results are embargoed until publication.

TABLE IV. Meta-Analysis of 10 U.S. Reports of Blood Lead Levels among Children Aged 1–5 years by Blood Lead Level Proportions

Blood lead level	% of BLLs (95% CI)	NHANES % (*p* value for difference)
≥ 10 μg/dL	52% (32–73)	8.9% (.0010)
≥ 15 μg/dL	32% (16–49)	2.7% (.0032)
≥ 20 μg/dL	21% (4–38)	1.1% (.0258)
≥ 25 μg/dL	14% (0–28)	0.5% (.0782)
≥ 30 μg/dL	9% (0–22)	0.4% (.2177)

Sensitivity Sub-Analysis

The geometric mean BLLs and proportions ≥ 10 μg/dL for children (n = 139) aged 1–5 years are presented by publication status, by standard 5-year calendar periods, and by industry in Table III. There was no statistically significant difference in geometric mean or proportion of BLLs ≥ 10 μg/dL between these groupings. Fifty-two percent of the children in the overall meta-analysis had BLLs ≥ 10 μg/dL. For these children, the proportions are shown by increasing BLLs up to ≥ 30 μg/dL along with the comparable NHANES III proportions in Table IV.

DISCUSSION

This meta-analysis suggests that children living in a household with a lead exposed worker are at increased risk of having elevated BLLs. Focusing on mean levels potentially obscures their predicament. While the overall meta-analysis of the ten reports from 1987 through 1994 resulted in a limited elevation of geometric mean BLL compared to the national average, it should be emphasized that 52% had BLLs ≥ 10 μg/dL, the current CDC action level. Additionally, 21% had BLLs ≥ 20 μg/dL and 9% had BLLs ≥ 30 μg/dL. The highest BLLs were found among the children of workers in the battery industry, followed by ceramics, radiator repair, laborers, construction, and firing ranges: all industries with known lead hazards.

The number of children at risk is not small. The National Institute for Occupational Safety and Health's (NIOSH) National Occupational Exposure Survey (NOES) estimated that 1,378,060 men and women in the U.S. were exposed to inorganic lead at work [NIOSH, 1990]. We estimate that about 723,500 of these actually worked in industries with potential take-home lead exposures and that about 480,000 (two thirds) of these exposed workers actually have risk of significant take-home exposures. In 1994, about 1 in 10 persons of 16 to 64 years of age was a member of a family with children under 6 years [Rawlings and Saluter, 1995]. Applying this average for the lead-exposed workers, we estimate that these lead exposed workers are household members of about 48,000 families with children under six. Some families will have more than one child under six. Based on this meta-analysis, about half of these children may have BLLs of 10 μg/dL or greater.

This report is based on a frail data base. First, the meta-analysis extrapolates from a small number of studies, ten, in a very limited number of industries, six, and a small number of participants, 139 children and 222 workers. Second, the participants may not be representatives of all workers and their children in these industries. Third, the industries included in this meta-analysis may not reflect other industries that have not been evaluated including: aircraft and other manufacturing, nonferrous and gray iron foundries, brass and copper rolling, semiconductors, aluminum extruded products, steel mills, and the U.S. armed forces [Maizlish and Rudolph, 1993]. More reports are needed to accurately describe the prevalence of elevated BLLs in the children of lead-exposed workers in these and other industries.

This analysis demonstrated no difference in the prevalence of elevated BLLs between children of parents who were merely known to be exposed to lead (55%) and children of parents who were known a priori to have an elevated BLL (50%). We are suspicious of these estimates. While they may be accurate if the worksites were chosen at random for study, it is more likely that other indicators pointed to these worksites as particularly having high lead exposures. A bias in this direction would lead us to overestimate the number of children at risk. More attention needs to be given to this issue, including the study of whether interventions that reduce lead levels in adults, such as improved respiratory protection, lead to reduced take-home lead exposure as would decontamination of clothing, vehicles, etc. A possible but less worrisome limitation is that the children may have been exposed to lead from sources other than parental take-home exposure. Many of the children in the NHANES population used for comparison did not have home lead exposures as high as the children of blue collar lead-exposed workers considered in this analysis. This would tend to make us overestimate the risk from take-home lead. We chose NHANES because it is the only available national comparison population. Reports that include comparisons with appropriate control children better identify the source of the lead exposure and the risk from take-home lead. Among the reports that included controls: Whelan et al. [1997] reported an odds ratio of 6.1 (95% CI 0.9–147.2) when comparing the proportion of lead-exposed workers' children under six years of age with BLLs $\geq$ 10 μg/dL (25.8%) to neighborhood controls (5.3%); Kaye et al. [1987] reported a significant difference ($P = .0001$) between the mean BLL for family members (of all ages) of exposed workers (10.2 μg/dL) and the mean of an unexposed group (6.2 μg/dL); and Gittleman et al. [1994] reported a significant difference ($P = .049$) between the mean BLL for the children (of all ages) of lead-exposed workers (22.4 μg/dL) and the mean for neighborhood control children (9.8 μg/dL). Although these results suggest that lead taken home from the workplace is the likely source of the children's exposure, further comparisons with BLLs from neighborhood control children are needed to better separate the proximate source of exposure.

CONCLUSIONS

This study estimates that about 48,000 children are at an increased risk of lead exposure by living in homes with lead exposed workers, and that about half may have BLLs of 10 μg/dL or greater. This number would represent about two and a half percent of the 890,000 children in the U.S. estimated to have BLLs of 10 μg/dL or greater. Failure to screen this population will probably mean that their lead poisoning will be missed because they might not live in neighborhoods or houses which would otherwise make them candidates for targeted screening. This study was limited by a dearth of data on the children of lead-exposed workers in many industries. Further, the estimates of the number of occupationally exposed children are frail. Carefully designed studies of children living in households of workers exposed to lead, delineated by industry, would aid in assessing the magnitude of their risk and in evaluating the effectiveness of interventions over time.

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