Effect of Interventions on Children's Blood Lead Levels

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Trail, Canada, has been the site of an active lead/zinc smelter for nearly a century. Since 1991, the Trail Community Lead Task Force has carried out blood lead screening, case management, education programs targeted at early childhood groups and the general community, community dust abatement, exposure pathways studies, and remedial trials. From 1989 through 1996, average blood lead levels of children tested for the first time declined at an average rate of 0.6 µg/dl/year, while blood lead levels in Canadian children not living near point sources appeared to be leveling off following the phase-out of leaded gasoline. Since there was no concurrent improvement in local environmental conditions during this time, it is possible that the continuing decline in Trail blood lead levels has been at least partly due to community-wide intervention programs. One year follow-up of children whose families received in-home educational visits, as well as assistance with home-based dust control measures, found that these specific interventions produced average blood lead changes of +0.5– -4.0 µg/dl, with statistically significant declines in 3 years out of 5. Education and dust control, particularly actions targeted toward higher risk children, appear to have served as effective and appropriate interim remedial measures while major source control measures have been implemented at the smelter site. *Key words:* blood lead, dust control, environmental lead exposure, health education, intervention, smelter contamination. *Environ Health Perspect* 106:79–83 (1998). [Online 21 January 1998]
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During the past two decades, numerous studies have found neurobehavioural effects in children in association with chronic low-level lead exposure (*1,2*). In 1991, the U.S. Centers for Disease Control released a statement establishing 15 µg/dl as the level at which individual children should receive nutritional and educational interventions and more frequent screening (*3*). Canadian guidelines now also suggest 15 µg/dl as an individual intervention level (*4*).

Trail, British Columbia, has been the site of a large active lead and zinc smelter for nearly a century. A study conducted in Trail in 1975 found average blood lead levels of 22 µg/dl in 1–3 year olds (*5,6*). A more detailed study in 1989 found a geometric mean of 13.1 µg/dl in 24–72 month olds, with 39.4% of the samples above 15 µg/dl (*7*). Recommendations of the study included the implementation of a comprehensive lead awareness and education campaign and provided the impetus for creating the Trail Community Lead Task Force.

By autumn of 1991, the Task Force had established a comprehensive childhood lead exposure prevention program. The program currently includes annual blood lead screening of children aged 6–60 months, case management, education programs targeted at early childhood groups and the general community, community dust abatement programs, exposure pathways studies, and intervention trials. We have previously reported on our work involving indoor dust control trials, ongoing soil treatment experiments, and trends in community blood lead levels from 1991 through 1994 (*8,9*). This paper examines in more detail the effect that community education, dust control, and case management efforts appear to have had on children's blood lead levels in Trail from 1991 through 1996. It is not possible to precisely quantify the impact of these interventions, as the measures were not withheld from matched control groups. Also, there is insufficient data to reliably establish the rate of decline in blood lead levels that was occurring in Trail prior to commencement of the intervention programs.

Methods

Blood lead screening. Blood sample collection and analysis techniques, as well as the age range of children tested, varied between earlier studies and the current program. In 1975, blood samples were collected from children 12–36 months of age by the fingerstick method and analyzed by anodic stripping voltametry. In 1989, fingerstick samples from children 24–72 months of age were analyzed by a graphite furnace atomic absorption spectrometer with Zeeman background correction (*10*). In 1990, there was no general blood lead survey; only children who had blood lead levels of 15 µg/dl or higher in 1989 were tested as a follow-up.

From 1991 through 1996, blood lead screening of children aged 6–60 months, who lived in the high exposure areas 2 and 3 as shown in Figure 1, was carried out annually. Each year approximately 340 eligible children have been identified through health unit immunization records, birth notices, British Colmbia Medical Services Plan data, local day care centers, and kindergarten lists. The participation rate for the blood testing clinics has ranged from 74 to 88%, with the higher participation rates occurring in later years. Families voluntarily attend the clinics at the Trail Lead Program office, where venous blood samples are drawn by an experienced pediatric phlebotomist after obtaining informed parental consent. Capillary samples are collected only in very rare instances when venipuncture fails or is not acceptable to the parent or child. Blood samples are collected during September each year, immediately after maximum summer exposure conditions are known to prevail.

Blood samples are analyzed using a graphite furnace atomic absorption spectrometer with Zeeman background correction (*10*). The following quality control (QC) procedures are used to verify the accuracy and precision of the blood lead measurements: random split samples from children are analyzed at both the study laboratory and a QC laboratory; replicate samples from adult volunteers are submitted weekly to the two labs; certified reference blood from the National Institute of Standards and Technology (NIST) is submitted weekly to the two labs; blood collection tubes and supplies are prescreened for contamination prior to the clinic; and all blood sample tracking data is double entered into a computerized database management system and cross-checked for accuracy. The annual blood lead clinics cost approximately $65,000 (Canadian).

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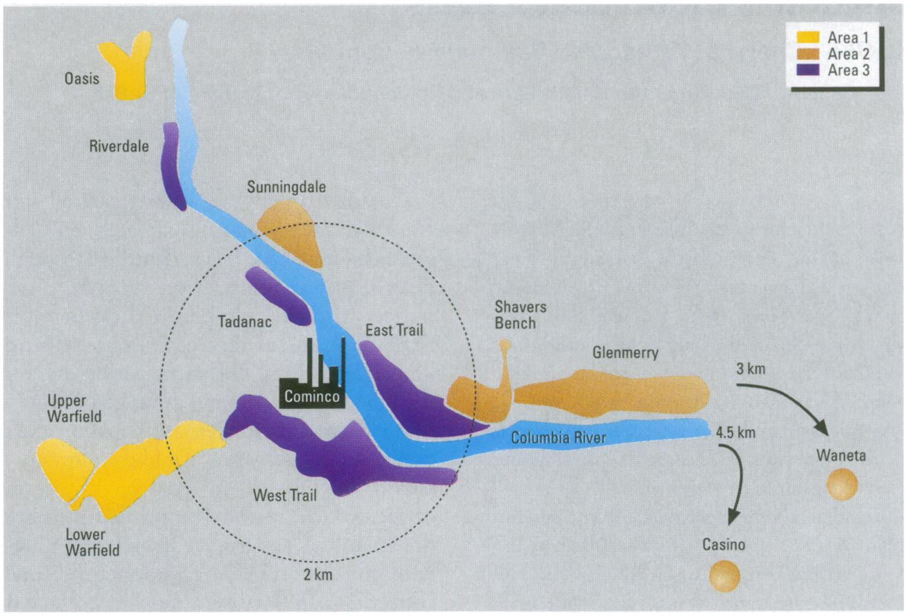

Figure 1. Trail residential areas.

Case management. Blood lead results of 15 μg/dl or higher for children 20 months of age and older, or greater than 10 μg/dl for children under 20 months of age trigger the family's inclusion in a case management program. The case management program began in 1991 and currently consists of more frequent blood lead testing; in-home counseling on exposure reduction measures such as dust control, hygiene, nutrition, and yard care; lead testing of bare ground, house dust, painted surfaces, etc., to highlight areas needing immediate attention; provision of entrance mats, sandboxes with clean sand and lids, ground cover materials, and house cleaning supplies or services; and assistance with paint abatement. Cleaning supplies may include mops, buckets, detergent, and loaned or purchased vacuum cleaners. Cleaning services include regular vacuuming, wet wiping, and mopping (*9*). Approximately $70,000 (Canadian) per year is spent on the case management programs.

Education. Exposure reduction messages are delivered directly to young children through semiannual visits to play schools, day care centers, and kindergarten classes. Puppets, a model house, and a unique demonstration of the need for careful hand washing are used to teach young children about hygiene, nutrition, and safe places to play. Materials and financial contributions are also provided to these groups to assist with cleaning and yard maintenance and to facilitate hand washing at their facilities.

During the annual fall blood screening clinics, families are offered hand soap, a doormat, and various written educational materials to reinforce the messages of good hygiene, good nutrition, and minimizing house dust. They are also provided with lead exposure reduction guidance tailored to such factors as age of their children and their area of residence. The Lead Program's public health nurse also meets with local physicians, makes presentations at prenatal classes, visits mothers in the hospital maternity ward, and visits families in their homes. Trail area community health nurses also include lead education as part of their regular well-baby visits.

The Lead Program's exposure reduction messages, as well as news about program activities and progress, are communicated to the general public through distribution of a newsletter three times per year to all residential mailing addresses in Trail, advertisements in local print and radio media, billboards, public displays, and quarterly

Table 1. Summary of educational contacts by the Trail Lead Program 1 September 1991–31 August 1992

Type of contact	Particulars of contact	No. of presentations or issues	No. of contacts with children	No. of contacts with adults	No. of minutes in contact per group or family
Contacts with educational groups	School bulletin boards	8	9,600	480	
	Artwork/circle time ideas	10	4,080	268	
	Meetings with or presentations to elementary school administrators, teachers, and students	55	525	55	25
	Meetings with or presentations to day care directors, instructors, and students	18	240	45	45
	Meetings with or presentations to Mom & Me leaders, mothers, and children	9	290	137	35
Subtotals		100	14,735	985	
Health promotion and case management contacts	Screening clinic anticipatory guidance	300	100	400	10
	Phone/letter family contacts	880	0	1,075	4
	Home/office counseling visits	275	150	350	40
	PHN contacts with families	240	30	300	10
	Meetings with health professionals	10	0	48	30
	Prenatal classes	11	0	154	30
Subtotals		1,716	280	2,327	
General community contacts	General community newsletter	1	0	7,050	
	School newsletters to parents	10	0	16,800	
	Local newspaper educational ads	6	0	81,840	
	Public meetings	12	0	10	60
	Miscellaneous functions (info booth, etc.)	5	50	360	3
Subtotals		34	4,100	106,060	
Grand totals		1,850	19,115	109,372	

PHN, public health nurse.

newsletters sent to parents through schools, play schools, and day care centers.

Table 1 provides a summary of the wide variety of contact types, groups reached, and number of contacts made in 1991–1992, which was the first year of operation of education and case management programs. Approximately $70,000 (Canadian) per year is spent on education programs.

Community dust abatement. Since 1992, the following dust control measures have been carried out in the Trail area: annual spraying of dust suppressant on unpaved alleys and parking surfaces; greening of bare public areas using turf or seed; covering of bare areas using asphalt, concrete, or gravel; and more frequent sweeping and washing of paved streets. The Rotary Club of Trail and other public groups have been instrumental in organizing and carrying out much of this work. An average of $17,500 (Canadian) has been spent each year since 1992, not including the cost of street cleaning.

Environmental monitoring. Soil data were obtained from studies conducted in 1977 (*6*), 1989 (*7*), and 1992 (*11*). In each of the studies, samples were collected from the top 2–3 cm of the soil profile and digested in nitric/perchloric acids prior to analysis for lead. In 1977, the samples were not sieved, whereas in 1989 and 1992, samples were passed through a 180-µm screen before analysis. This report considers samples collected from the same geographic areas in each of the 3 study years.

Data for lead in suspended particulate, lead in dust fall, and number of days with rain were collected by the smelter company. Suspended particulate was collected for 24 hr every 6 days by two high volume air samplers located in the immediate Trail area. Dust fall was collected monthly in plastic jars located at nine sites in the immediate Trail area; however, analysis of dust fall samples for lead did not start until 1991. The sampling equipment, sampling sites, analytical techniques, and quality control procedures for suspended particulate and dust fall data meet British Columbia Ministry of Environment (BCMoE) requirements. A quality control sampling station is operated in Trail by the BCMoE to verify results obtained by the smelter company. Data from the audit station were not used in this analysis, as the station did not operate during part of 1995 and 1996 due to construction activities near the site. Precipitation was recorded at the smelter site as part of the requirements of a weather observation program operated by the Atmospheric Environment Service (Environment Canada).

Data analysis. Analyses were conducted to examine the effects of both the general community-wide intervention efforts and the more specific one-on-one case management efforts. To distinguish between these effects, we conducted separate analyses of blood lead data for children tested for the first time in each year and for children who received repeat testing subsequent to in-home case management intervention. The former analysis excluded children with older siblings who had been tested previously, and the latter analysis excluded those whose families had already received case management intervention for older siblings.

Frequency plots of blood and environmental lead data indicated that the data were log-normally distributed. Averages are expressed as geometric means, and hypothesis testing and regression analyses were performed on natural log-transformed data. Age and area adjustment of log-transformed blood lead data was performed using analysis of covariance (*12*) to compensate for year-to-year differences in the age and area of residence distributions of participants where necessary.

Results

Figure 2 shows the trend in geometric mean blood lead levels for children tested for the first time in each year from 1989 through 1996 (there was no blood lead survey in 1990). The age and area distributions of children tested varied significantly ($p<0.01$) from year to year, so age and area-adjusted blood lead averages are presented. In multiple regression analysis with blood lead as the dependent variable, the year of testing entered into the regression model even after adjustment for age and area (see Table 2). The regression showed a declining trend of 0.6 µg/dl (or about 5%) per year.

Changes in local environmental lead levels and weather conditions were investigated to determine whether the 0.6 µg/dl/year decline in average blood lead levels in Trail might be due to improvements in local conditions. Table 3 shows the average soil lead levels in Trail from 1977 to 1992. The differences between years were not statistically significant, even when paired analysis by postal codes was conducted on the 1975 and 1989 data (*13*). Therefore, the decline in blood lead levels from 1989 to 1996 is not due to any improvement in soil lead levels.

In infants and toddlers, where skeletal lead contributes a relatively small portion of total blood lead concentration, lead in blood is generally thought to reflect fairly recent exposure (i.e., the past 30 days) (*14*). Many of the children tested annually in Trail, particularly those aged 3–5 years, have been chronically exposed to lead for several years, and their present blood lead levels are much more dependent upon longer term past exposures. However, the year-to-year variability in average blood lead levels in Trail might be expected to correlate with exposure conditions during the summer months prior to each annual blood testing clinic. We therefore chose to look at environmental and weather conditions during the summers preceding each of the annual blood lead clinics.

Possible relationships between blood lead and air lead, dust fall lead, and the number of days without rainfall in the June to August period were examined. In multiple regression, no statistically significant correlations were found between average blood lead level and air lead, dust fall lead, or number of dry days for either the whole summer period or for any subset of it. Table 4 shows that there clearly has not been any trend in August values for ambient air lead, dust fall lead, or number of dry days over the 1989–1996 period. Therefore, the decline in blood lead levels from 1989 to 1996 does not appear to be due to changes in summer air lead, dust fall lead, or weather conditions.

Table 5 presents results for children who had elevated blood lead levels (≥15 µg/dl)

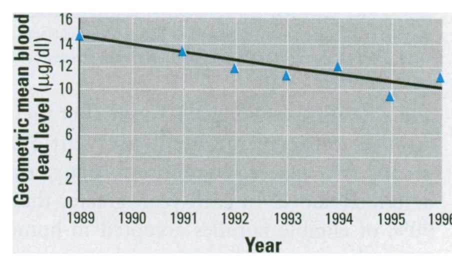

Figure 2. Age and area-adjusted geometric mean blood lead levels of children tested for the first time, by year. The regression line represents 1989–1996 means.

Table 2. Regression model for effect of year on blood lead

Independent variable	Regression coefficient	Standardized coefficient	*p*-Value
Age	0.0670	2.52	<0.0001
Age^2	0.00212	-5.07	<0.0001
Age^3	0.000195	2.65	<0.0001
Area	0.203	0.240	<0.0001
Year	-0.053	-0.271	<0.0001

The dependent variable is ln(blood lead); the multiple correlation coefficient = 0.39.

Table 3. Geometric mean soil lead concentration in Trail, British Columbia

Year	Number of samples	Soil lead (ppm)	Reference
1977	153	790[a]	(*6*)
1989	119	725	(*7*)
1992	213	713	(*11*)

[a]Samples were not sieved prior to analysis and may be biased low in comparison to 1989 and 1992 data.

Table 4. Blood lead screening results and concurrent environmental conditions

Parameter	1989	1991	1992	1993	1994	1995	1996
Blood lead (μg/dl)[a]							
No. of children	169	197	118	99	95	76	46
Age and area-adjusted geometric mean[b]	14.5	13.4	11.9	11.3	12.1	9.5	11.0
Lead in suspended particulate (μg/m^3)							
Geometric mean (August)	0.98	1.1	2.7	0.51	1.5	0.71	1.8
Lead in dust fall (mg/m^2/day)							
Geometric mean (August)	NA	2.6	1.7	1.4	1.4	0.81	2.4
Weather							
No. of days without rain in August	13	22	25	19	27	19	24

NA, not available.
[a]September clinic; children in areas 2 and 3 who were tested for the first time.
[b]Blood lead means have been age- and area-adjusted to allow comparison by year.

Table 5. Children's blood lead levels following case management intervention

Year children received intervention	Number of children in group	Average age at enrollment (months)	Average initial blood lead[a] (μg/dl)	Average change in blood lead in group 1 year later (μg/dl)	Paired *t*-test *p*-value for change
Children receiving intervention[b]					
1991	77	39	19.8	-4.0	<0.0001
1992	34	33	18.4	-3.1	<0.0001
1993	14	21	20.4	-2.3	0.10
1994	25	27	18.2	-3.1	0.0001
1995	14	30	17.4	+0.5	0.71
Children who did not receive intervention					
1989	55	48	19.8	+1.2	0.16

[a]All data in this table are for children who had an elevated blood lead level (≥15 μg/dl) prior to intervention.
[b]Data in this section are for children whose families received case management intervention for the first time.

and who were tested again 1 year after their families received targeted interventions under the case management program described above. In each year, greater than 90% of eligible families accepted in-home counseling and assistance with exposure reduction measures; thus, the number of children with elevated blood lead levels who did not receive interventions in each year is very small. Therefore, the only available comparison is with the children who had elevated blood lead levels in 1989, as interventions were not provided in that year. Those children showed an average increase of 1.2 μg/dl when tested 1 year later. The difference was not statistically significant. In contrast, when the blood lead levels of counseled children have been rechecked 1 year later, the average has usually declined by statistically significant amounts (2.3–4.0 μg/dl). The notable exception was from 1995 to 1996, when the blood lead levels of the small number of children who received interventions for the first time did not change significantly. There was no significant relationship between age and change in blood lead level among the children involved. Therefore, despite the declining average age of children enrolled in case management for the first time, there was no need to age-adjust the blood lead data.

Discussion

There does not appear to have been any increase in the rate of decline in blood lead levels of Trail children following the introduction of interventions in late 1991. As mentioned above, there is insufficient data to reliably establish the rate of decline in blood lead levels that was occurring in Trail prior to 1991. However, the constant and gradual decline seen in blood lead levels of Trail children from 1989 through 1996 roughly parallels a general worldwide drop in blood lead levels seen during the period from about 1976 through 1994 (*15–19*). In fact, the global rate of decline has been about 0.8–1.5 μg/dl/year, rather than the 0.6 μg/dl/year seen in Trail. The global decline is thought to be due to such actions as the phase out of lead in gasoline and paint, the discontinued use of lead solder in food tins, and reductions in air emissions from industrial plants. In Canada, where leaded gasoline was eliminated by 1990, the Ontario Blood Lead Study found that average blood lead levels in children not living near point sources declined by about 1.3 μg/dl/year from 1984 to 1990 and then appeared to level off (*20*). Therefore, it appears that the decline in blood lead levels in Trail from 1991 through 1996 must be at least partly due to local changes. As presented above, there was no corresponding improvement in local environmental conditions during this period. Therefore, it is possible that the continuing decline in Trail children's blood lead levels may be at least partly due to the implementation of (and annual improvements in) community-wide intervention programs.

In the 1-year follow-up of Trail children whose families received in-home educational visits, as well as assistance with exposure reduction measures, we found that these specific interventions produced average blood lead changes of +0.5– -4.0 μg/dl, with statistically significant declines in 3 years out of 5. A number of other published studies have also examined the effects of educational efforts and/or assistance with measures such as house cleaning or ground cover improvement. A study of in-home education efforts in Milwaukee, Wisconsin, involved 431 children up to 6 years of age with initial blood lead levels of 20–24 μg/dl (*21*). Advice on nutrition, behavior change, and housekeeping was provided to families of 195 children in this group. The remaining 236 children did not receive visits, either because they were identified before the education visits were being offered or because their families could not be contacted. The mean decline in blood lead in the group receiving visits was 4 μg/dl. The net difference in blood lead change between groups, after adjustment for age and seasonal differences, was 3 μg/dl (p = 0.001). Another group of 28 Milwaukee children with initial blood lead levels of 25–40 μg/dl received the same home visit as in the previous study, plus a visit from a public health nurse (PHN) who conducted a child health assessment and answered any questions about lead (*21*). There was no control group in this study, as virtually all families eligible for this program were contacted. The mean decline in blood lead in this group was 6 μg/dl, which suggests that greater declines may be achieved when initial blood lead levels are higher, or that the second visit by the PHN may have provided additional benefit.

A study in the former secondary lead smelter town of Granite City, Illinois, involved 78 children under 6 years of age who had initial blood lead levels greater than 9 μg/dl (*22*). The parents of these children received in-home counseling visits lasting about 30–45 minutes. The visits included advice on hand washing, nutrition, housekeeping, hand-to-mouth activity, and simple paint abatement where indicated. There was no control group. At 1 year follow-up, the average blood lead level had declined by 5 μg/dl, which is a particularly noteworthy decrease considering that the average initial blood lead level was only 14.6 μg/dl.

A controlled trial of regular wet mopping of floors, combined with advice regarding hand washing, housekeeping, and lead "hot spot" avoidance, found that the average blood lead level of the group receiving intervention fell from 38.6 μg/dl to 31.7 μg/dl (a drop of 6.9 μg/dl), while that of the control group fell by only 0.7 μg/dl (*23*).

A more recent study found that a combination of interior painted surface cleanup, house cleanup with a HEPA (high efficiency particulate air) vacuum, mopping with high phosphate detergent, some carpet removal, covering of bare soil with sod or bark, provision of clean sand boxes, provision of household cleaning supplies, and provision of dust control information was effective in preventing a seasonal rise in blood lead levels (*24*).

A controlled trial of regular HEPA vacuuming of interior floors in Trail failed to show a clinically significant impact on either blood lead or floor lead levels (*8*). However, an uncontrolled follow-up study suggested that a combination of regular HEPA vacuuming, wet mopping, exposure reduction advice, and assistance with ground cover improvement was successful in reducing the summer seasonal rise in blood lead levels and in preventing the seasonal rise in floor lead loadings (*9*).

Overall, this report suggests that comprehensive, community-wide interventions such as education, greening, and other dust control measures may have had an impact on blood lead levels in Trail. However, the lack of a control group or adequate baseline data make it impossible to conclude that these actions have had a measurable impact. On the other hand, interventions specifically targeted toward children with elevated blood lead levels do appear to have an impact. Targeted interventions such as in-home counseling and assistance with home-based exposure reduction measures have been associated with reductions in blood lead levels in Trail, as well as at other sites. These targeted interventions have served as effective and appropriate interim measures in Trail while the smelter company has been implementing critical source control actions, such as the reduction of fugitive emissions and the construction of a new state-of-the-art lead smelter. It is recommended that in-home counseling and assistance with home-based exposure reduction activities be implemented and studied as preventive measures for infants, rather than focusing only on children whose blood lead levels are already elevated.

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