Follow-up of Children Overexposed to Lead*

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The purpose of this study is to assess the nature and magnitude of the deleterious health effects of subclinical over-exposure to lead in children. The study stems from concerns about the impact on the health of children in city slums who ingest leaded paint without overt evidence of poisoning and the health implication of rising levels of lead in the environment from automotive emissions. The study sample was derived mainly from a registry of children on whom blood lead determinations had been made by the New York City Department of Health and was supplemented by siblings of the registry cases and children from a lead belt area who had extractions of deciduous teeth in dental clinics. Information was obtained through parental interview, medical records, and psychometric evaluation. The data show that deleterious health effects occur in children who were treated for severe lead poisoning and in children without diagnosed lead poisoning who had elevated blood leads ($\geq$0.06 mg-%). In the absence of diagnosed lead poisoning or elevated blood leads, excess lead exposure, measured in terms of high levels of lead in teeth, was not associated with deleterious health effects.

Introduction

The purpose of this study is to determine whether children who are overexposed to lead at levels insufficient to produce acute poisoning suffer subsequent deleterious health effects. The study was undertaken because there is a concern over the possible injury to health from the rising levels of lead in the environment, primarily due to automobile exhausts, and the possibility that large numbers of children in areas with deteriorated housing who are subclinically overexposed to lead may also suffer ill effects.

Sequelae to severe forms of poisoning such as encephalopathy are well established (*1–4*). Although there is a substantial incidence of overexposure to lead among ghetto children as evidenced by elevated blood leads (*5*) and elevated tooth leads (*6*), there is little evidence relating to the question of whether overexposure in the absence of overt poisoning is harmful.

The primary focus of the study was a

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comparison of children who had no history of overt lead poisoning but who differed substantially in their cumulative lead exposure as measured by the concentration of lead in deciduous teeth. The study also included children who had clinical lead poisoning as a positive control. These groups were compared on the basis of validated illness experience, psychometric tests, and academic performance.

Materials and Methods

The study sample was drawn primarily from the New York City Health Department blood lead registry for 1961–1967, which included about 4000 children on whom the Health Department had performed one or more blood lead measurements. The Health Department has been the main laboratory resource in New York City for blood lead assays for suspected cases of lead exposure from hospitals, out-patient clinics, and Child Health Centers of the New York City Department of Health.

In addition to the cases located from the lead registry, the study includes siblings of the registry cases and a sample of children who had tooth extractions in dental clinics in an area of the City with a relatively high incidence of lead poisoning. Subjects from all three sources were included in the study sample whenever teeth became available for assay of lead.

Location methods for the lead registry cases were similar to those used in another study (*7*) and included checks of post office, school, social service, telephone, hospital, and board of health resources. Case location was only about 40% successful, largely because of the high mobility of this population and the fact that only a minority of the Health Department registry reports included a parental name, without which several prime case finding resources could not be used. However, located subjects were representative of the lead registry with respect to the proportion with elevated blood leads, the proportion hospitalized for lead poisoning, the age at blood lead determination, and the sex distribution of cases. The located cases have had the following procedures: (1) interview of the mother of the case by a field worker for illness experience and socioeconomic characteristics, (2) collection and analysis for lead of shed decidious teeth, (3) search of hospital and physician records to validate illness experience, (4) collection of school records.

The New York City public schools use a standard form which contains yearly records of grades, standardized test scores, teacher ratings of social-behavioral characteristics, indications of remedial or psychological help, visual and audiometric screening reports, height and weight measurements, and school attendance records.

A proportion of the cases were brought in for psychometric examination. Children were not tested until they reached about seven years of age, since the reliability and stability of test scores for younger children are low. To control the effects of age upon test performance, only tests with adequate age norms were used. Measures were chosen in the areas of: (1) verbal and nonverbal intelligence, Wechsler Intelligence Scale for Children (WISC); (2) reading and spelling achievement, Wide Range Achievement Test (WRAT); (3) perceptual–motor performance, Bender Gestalt Test, Koppitz scoring (*8*); figure drawing test, Harris scoring (*9*); (4) fine motor coordination, Purdue Pegboard Test (*10*).

The method for assaying teeth for lead has been reported elsewhere (*11*). Ashed teeth were dissolved in concentrated nitric acid; the lead was separated from the calcium and phosphate with Aliquat Bromide and then extracted into hydrochloric acid and analyzed by atomic absorption spectrometry. The lead content of teeth was expressed in terms of micrograms of lead per gram of tooth ash.

The frequency distribution of lead levels in extracted teeth obtained from the dental clinics is shown in Figure 1. The numbers of molars, canines, and incisors were, respectively, 510, 20, and 96. The cumulative frequency distribution was log-normal with a median of 11.5 $\mu g/g$ of tooth ash and a large

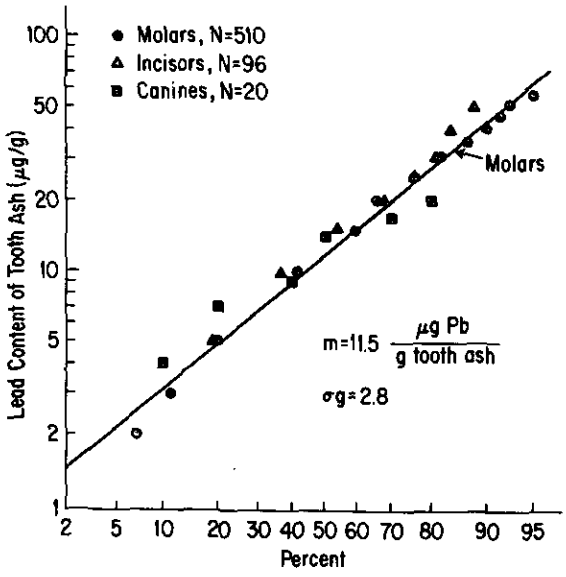

FIGURE 1. Cumulative per cent distribution of lead concentration in extracted deciduous teeth.

geometric standard deviation of 2.8. Although the sample contained few extracted incisors and canines relative to molars it is evident that the lead contents of the different tooth types are similar.

Results

This report deals with the data obtained on a total of 371 subjects including 300 from the lead registry, 48 siblings, and 23 dental clinic subjects. Of the 371 subjects, 159 were brought into the clinic for psychometric testing. The subjects ranged in age at follow-up from 5 to 15, with a mean age of 9.0 years. The mean age at blood lead test was 2.3 years, over half being tested between 1.5 and 2.5 years of age. The interval from blood test to follow-up ranged from 3 to 11 years, with a mean of 6.7 years (S.D. = 1.6).

For purposes of analysis the study sample was divided into two broad categories. Those that were hospitalized for overt poisoning and received chelation therapy and those that did not have diagnosed lead poisoning and therefore received no chelation therapy. The treated poisoning cases were subdivided according to whether the case had encephalopathy or not. The untreated, nonpoisoned group were subdivided into three categories: those with blood leads of 0.06 mg-% or greater and those with blood leads below this level, substratified according to whether the case had high or low levels of tooth lead. This stratification provided a spectrum of cases which ranged from individuals with severe lead poisoning to those that had no evidence of either poisoning or excessive accumulative exposure to lead. Thus group I consisted of cases with encephalopathy, group II of other cases with treated lead poisoning, group III of subjects with elevated blood leads but no treatment for lead poisoning, group IV of subjects with high tooth leads but low blood leads, and group V of subjects with low tooth leads and low blood leads. However half of groups IV and V were siblings or dental clinic subjects, who were without blood lead assays.

Table 1 shows the demographic and social characteristics of the study sample according to the various categories of lead exposure. There were only six cases of encephalopathy in the study sample to date but the other categories ranged from 57 to 154 cases each. There was a marked predominance of blacks in all of the categories, with relatively few Puerto Ricans and very few whites. About half the cases had no father in the household and were on welfare. As expected, income was low, the families were large, and living quarters were relatively crowded. Most of the families in all the exposure groups reported living in deteriorated housing when the child was young; 72% indicated peeling paint and 73% broken plaster then. The schooling of mothers and fathers averaged about ten and eight years, respectively. The groups did not differ with respect to the frequency of birth problems.

Significance tests for differences among the study groups are based on comparisons with group V. Since the exposure groups differed somewhat in ethnic composition and sex ratio, analyses were performed with stratification for these factors by using

Table 1. Descriptive characteristics by exposure group.

	Hospitalized lead poisoning with chelation therapy		No diagnosis of lead poisoning and no chelation therapy		
	Encephalopathy I	Other II	High blood, high or low tooth III	Low blood, high tooth IV	Low blood, low tooth V
Number of cases	6	154	65	57	89
Median blood lead, mg-%	0.11	0.08	0.07	0.04	0.04
Median tooth lead, μg Pb/g ash	32	29	33	58	12
Negro/Puerto Rican/white, %	83/0/17	77/17/6	74/18/8	53/26/21	76/17/7
Male, %	83	52	62	46	49
One-parent family, %	33	52	46	46	49
Welfare support, %	33	55	47	51	44
Income per capita/week (mean), $	24	22	22	24	22
Mother's education (mean grade)	11.8	9.4	9.7	9.6	10.4
No. children in family (mean)	2.5	4.2	4.5	4.7	4.3
Living density, rooms/occupant (mean)	1.5	1.0	1.0	0.9	0.9
High risk birth, % [a]	17	5	9	9	14

[a] Includes birth weight ≤ 2000 g, Apgar score ≤ 6, and asphyxia.

analysis of variance and the Mantel-Haenszel summary chi-square (*12*) techniques as appropriate. The *P* values presented are those obtained when controlling for race only, since the values when controlling for sex and race were virtually identical.

Table 2 shows the mental disorders that were validated by a professional diagnosis. As expected, a substantial proportion of the encephalopathy cases showed evidence of brain damage. Four of the six cases were diagnosed as having mental retardation ($P = 0.001$). Some of these also had diagnoses of organic brain syndrome, seizure disorders, and behavior disorders, but in this tabulation only one diagnosis per case is listed.

The rates in Table 2 of all mental disorders combined yield risks, relative to group V, of 2.5 ($P = 0.07$) in group II and of 4.1 ($P = 0.01$) in group III. There were no differences in mental disorders between groups IV and V.

Table 3 shows the results of the psychometric tests administered to the subjects individually in the clinic examination program. The three encephalopathy cases showed markedly retarded intellectual performance on the full-scale IQ test ($P = 0.01$). The only other group showing retarded performance compared to group V was Group III whose mean was seven points below group V ($P = 0.10$). The pattern of intelligence scores was almost identical in

Table 2. Diagnosed mental disorders: by exposure group.

	Hospitalized lead poisoning with chelation therapy		No diagnosis of lead poisoning and no chelation therapy		
	Encephalopathy I	Other II	High blood, high or low tooth III	Low blood, high tooth IV	Low blood, low tooth, V
Number of cases	6	154	65	57	89
Mental retardation, %	66.7	2.6	3.1	0	0
Organic brain syndrome, %	0	0.6	3.1	0	0
Seizure disorders, %	0	1.3	7.7	1.8	0
Behavior disorder, %	0	3.9	4.6	1.8	4.5
Other, %	0	2.6	0	0	0
All mental cases, %	66.7	11.0	18.5	3.5	4.5

Table 3. Psychological test results: means by exposure group.

	Hospitalized lead poisoning with chelation therapy		No diagnosis of lead poisoning and no chelation therapy		
	Encephalopathy I	Other II	High blood, high or low tooth III	Low blood, high tooth IV	Low blood, low tooth, V
Number of cases	3	68	25	24	39
Age at testing, yr.	9.7	9.0	9.0	8.5	9.7
Intelligence quotient, full scale	77.0	96.2	92.4	103.7	98.9
Bender Gestalt quotient	67.0	84.2	79.0	96.1	85.5
Figure drawing quotient	69.7	90.7	87.4	93.0	92.7
Purdue Pegboard error score	7.0	1.7	1.5	1.3	1.9
Overall organic rating	3.0	1.0	1.4	0.6	0.7

the verbal and performance areas in all groups.

The two measures of perceptual-motor deficits showed a pattern similar to that of intelligence. On the Bender Gestalt test, group I averaged 18 points below group V ($P = 0.005$) and group III averaged seven points below group V. The deficits on the figure drawing test average 23 points ($P = 0.02$) and five points in groups I and III, respectively, relative to group V. There was evidence from the Purdue Pegboard of fine motor incoordination only in group I.

The clinical psychologist made a composite rating of organic impairment on each subject on a five point scale without knowledge of the lead exposure. A comparison of the means, which are presented in Table 3, indicates that group I ($P = 0.001$) and group III ($P = 0.01$) were rated as having significantly more organic involvement than the controls. The treated poisoning cases (group II) did not show a significant difference from group V, nor did the high tooth subjects (Group IV).

Table 4 shows the data on school performance. The average number of school grades completed ranged from 3.3 to 4.8. Examination of the school records showed that most scholastic and behavior problems had already become apparent by the third grade and that the number of completed grades had no appreciable effect on group differences. There were no differences between groups IV and V in any of the factors derived from school records. There were

Table 4. School data: by exposure group.

	Hospitalized lead poisoning with chelation therapy		No diagnosis of lead poisoning and no chelation therapy		
	Encephalopathy I	Other II	High blood, high or low tooth III	Low blood, high tooth IV	Low blood, low tooth, V
Number of cases	6	125	51	44	70
No. of grades completed (mean)	4.8	3.3	4.0	3.3	3.8
Special class, %	50 [a]	7	16 [a]	2	3
Failed a grade, %	20	14	22 [a]	12	7
Academic gradepoint $\leq$ 1.8, %	—	7	17	7	7
Psychologic referral, %	50 [a]	13 [a]	19 [a]	2	4
Behavior problems, %	33	15	20	7	10
Attention and concentration problems, %	67 [a]	15 [a]	16	5	6
Incoordination, %	50 [a]	4	8	0	3
Poor motivation, %	0	6	2	9	12

[a] Comparison with the low blood, low tooth group is significant, $P \leq 0.05$.

significantly greater proportions of individuals in groups I and III relative to group V who were in special classes because of mental retardation or psychological disorders. Groups I, II, and III showed substantially higher proportions of individuals with psychological referrals, behavior, and attention and concentration problems relative to group V. Except for group I, there were no significant differences in reports of incoordination.

As indicated by the above data, group III showed substantially higher levels of abnormality relative to group V in terms of mental disorders, psychometric tests, and school records. A further examination of this group showed that 28 (43%) of the 65 subjects were asymptomatic at the time of the blood lead determination. A few of the symptomatic cases in Group III should probably have been diagnosed as lead poisoning and given chelation therapy. Other symptomatic cases were equivocal with respect to lead poisoning. For example, four individuals presented with convulsions and were diagnosed both at the time of the lead determination and subsequently as seizure disorders. These symptomatic and asymptomatic cases in group III are compared in Table 5 to group V. As shown in Table 5, most of the abnormalities in group III are accounted for by the symptomatic cases, although there is still a residue of difference in diagnosed mental disorders and in the school data.

Other health patterns were evaluated as part of the study. The five groups did not differ in frequency of hospitalized illness of any type or in total number of hospitalizations. Heights and weights were essentially normal and did not differ among study groups. Marked visual and hearing deficits were found infrequently in the school screening records and occurred equally in all groups. Average school absences were also similar among study groups.

Table 5. Medical, clinic, and school results for untreated asymptomatic and symptomatic high-blood-lead groups and the unexposed control group.

	High blood lead		Low blood, low tooth
	Asympt.	Sympt.	
Number of cases	28	37	90
Diagnosed disorders, %			
Mental retardation	0	3	0
Organic brain syndrome	4	5	0
Seizure disorder	0	11[a]	0
Behavior disorder	11	3	4
Other	0	0	0
All mental cases	14[b]	22[a]	4
Psychological tests (means)			
IQ, full scale	100	87[a]	99
Bender Gestalt	85	76	86
Figure drawing	91	86	93
Purdue Pegboard	0.4	2.5	1.9
Overall organic rating	1.0	1.7[a]	0.7
School Data, %			
Special class	9	19[a]	3
Failed grade	14	27[a]	7
Behavior problems	18	19	10
Psychologic referral	22[a]	17[a]	4
Attention and concentration problems	23[a]	10	6
Incoordination	0	13	3

[a] Comparison with the control group is significant, $P \leq 0.05$.

[b] Comparison with the control group is significant, $P \leq 0.10$.

Discussion

Comparisons of groups IV and V showed no evidence of deleterious health effects in children who had no history of lead poisoning but who had received lead exposure as measured by high tooth lead concentrations.

The use of lead levels in teeth as a measure of exposure has been reported by others (*6,13,14*). In this program a parallel study on baboons strongly supports the utility of deciduous teeth as a measure of lead exposure in terms of the high degree of persistence of lead deposited in teeth and the proportionality of the deposition to administered dose (*15*). The relative difference in tooth lead levels in groups IV and V represents a factor of five in cumulative intake. These findings raise some doubts about the significance to health within the first ten years of life of rising levels of lead in the general environment from automobile exhausts. However, it is evident that the population under study is one which is

strongly subjected to a variety of deleterious environmental factors which may mask effects of increased lead exposure in the absence of overt poisoning.

The treated lead poisoning cases (Group II) showed significant differences from group V with respect to diagnosed mental disorders and in their school performance as evidenced by psychological referrals and problems of attention and concentration. The untreated cases with elevated blood leads (group III) represented a mixed group. Those who were sick at the time of the elevated blood leads did very poorly. Even those cases who were asymptomatic at the time of the elevated blood leads had evidence of health impairment. These findings raise the possibility that children with elevated blood lead should be treated by chelation therapy regardless of whether they are asymptomatic and irrespective of whether they have symptoms which support a definite diagnosis of lead poisoning.

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