Lead Intoxication in Infancy

Michael W. Shannon, MD, MPH,*‡§ and John W. Graef, MD‡§

ABSTRACT. Four years of experience in the evaluation and management of lead intoxication in the first year of life were reviewed. This study was conducted in a lead referral program within the state of Massachusetts, whose comprehensive lead laws include extensive (and now mandatory) lead screening of all children. Over the period of study, 50 (14%) of 370 new patients enrolled in the program were infants aged 12 months or younger. Median age of these infants was 11 months (range 1 through 12 months). Mean peak lead level was 39.0 μg/dL while the mean peak erythrocyte protoporphyrin concentration was 111.9 μg/dL of whole blood. Thirty-two percent of infants were ambulatory at the time lead intoxication was diagnosed; only 24% had a history of pica. Twenty-six percent of parents were welfare dependent. Apparent sources of plumbism included household renovation (n = 20), direct ingestion of paint chips (n = 10), formula preparation with lead-contaminated water (n = 9), lead dust importation (n = 1), and congenital exposure to elevated maternal lead level (n = 1). In 9 cases the source was not found. When this profile was compared with that of a randomly selected group of 47 children aged 18 through 30 months, who were seen in the lead program during the same interval, apparent sources of intoxication in the older group were paint chip ingestion (n = 41), household renovation (n = 2), and unknown (n = 4) ($P < .0001$). On the basis of these data, it is concluded that lead intoxication in infants is common and has significantly different origins from that in toddlers. Lead intoxication from infant formula reconstituted with contaminated water may account for many of these cases. These findings support recommendations that lead screening begin at the age of 6 months for children with any likelihood of lead exposure. *Pediatrics* 1992;89:87–90; *lead intoxication, infant, screening.*

Lead is one of the most widespread environmental toxins facing American children. Well-controlled studies continue to accumulate evidence that, even at what were once considered low levels of exposure, apparently irreversible adverse health effects, particularly to the central nervous system, occur in young children.[1–4] The increasing concern about children with lower levels of lead exposure has forced a reexamination of the epidemiology of this disease. Data from 1950 to 1980 focused attention on the ambulatory toddler, 12 to 36 months of age, living in older, usually dilapidated housing, in whom high blood levels of lead developed after ingestion of paint chips (pica).[5] Lead poisoning in infants was considered a rarity, usually resulting from unique circumstances such as inappropriate use of lead-based body cosmetics or direct administration of lead-containing folk medicines.[6,7] This view has had several unfortunate consequences: (1) it discourages pediatricians from initiating lead screening until the second year of life; (2) it discourages lead screening of children from rural and suburban areas where dilapidated housing is less common; and (3) when plumbism is discovered, it is assumed the intoxication is the result of pica and alternative sources of lead are not investigated.

Little is known about the prevalence and pattern of lead poisoning in infants. The Second National Health and Nutrition Examination Survey (1976 to 1980) included children from age 6 months but the sample size was small and results were included in the data of children up to age 2 years.[8] However, since 1978 the Centers for Disease Control has recommended screening high-risk children beginning at 6 months of age.[9] The American Academy of Pediatrics, while noting that some children might be at risk as early as 6 months of age, has recommended initial screening to coincide with the first routine hematocrit at 9 to 12 months.[6] The Commonwealth of Massachusetts has offered voluntary statewide lead screening for children from age 1 year up to 6 years since the passage of its Lead Poison Prevention Act in 1971. A revision of this law in 1987 included a provision for mandatory screening according to a schedule to be determined by state public health authorities in consultation with interested medical groups. This schedule included the requirement that children at "high risk," as determined by the likelihood of direct exposure to lead hazards, be screened at least every 6 months, beginning at 6 months of age.

We recently noted a significant number of young infants being referred to our Lead/Toxicology Program, perhaps in part because of the increasing surveillance of Massachusetts children of all ages. Therefore, we undertook this study to examine more closely the patterns of childhood plumbism seen in Massachusetts in the first year of life.

METHODS

For this study, the hospital charts of all patients through the age of 12 months seen in the Lead/Toxicology Program of The Children's Hospital, Boston, from 1987 through 1990 were reviewed. While this clinic is a referral program for the evaluation and management of children with any environmental intoxication, re-

From the * Division of Emergency Medicine and ‡ Program in Clinical Pharmacology/Toxicology, The Children's Hospital, Department of Pediatrics, Harvard Medical School, and § The Massachusetts Poison Control System, Boston.

Received for publication Apr 8, 1991; accepted May 31, 1991.
Presented, in part, at the 31st Annual Meeting of the Ambulatory Pediatric Association, New Orleans, LA, April 1991.

Reprint requests to (M.W.S.) Children's Hospital, 300 Longwood Ave, Boston, MA 02115.

ferrals of children with plumbism predominate. With occasional exceptions, children with lead intoxication were eligible for enrollment if their venous blood lead levels exceeded 25 μg/dL of whole blood. This value was reduced in 1990 to accept children with lead levels exceeding 20 μg/dL.

At the initial clinic visit, a thorough environmental history was obtained which included previously recorded lead levels, a description of the patient's residence, results of any environmental inspections (paint, water, and/or soil analysis), blood lead levels of siblings, recent renovation, oral habits of the child, recent changes in behavior, time spent elsewhere, occupations of both parents, water sources, and water intake. For infants younger than 11 months of age, a detailed history of formula preparation practices was also obtained.

Laboratory assessment of patients included measurement of whole blood lead and erythrocyte protoporphyrin concentrations; complete blood and reticulocyte counts; serum iron level; total iron-binding capacity (TIBC); ferritin, blood urea nitrogen, and serum creatinine levels; and urinalysis. Blood and water lead analyses were performed by atomic absorption spectrophotometer (Perkins-Elmer Corp, Norwalk, CT). Radiographic evaluation on the first clinic visit usually included knee and abdominal radiographs (for evaluation of growth arrest lines or radiopaque gastrointestinal densities). On the basis of these data and after state-mandated inspection of the home for lead hazards, a judgment of the likely source of lead was made and medical management (including education on preventing further exposure) was provided.

To compare the origins and clinical profile of infants with that of older children managed in our program, we randomly selected (on the basis of alphabetical listing) 47 children aged 18 through 30 months who attended the Lead/Toxicology Program during the same study interval, extracting similar demographic and clinical data.

Statistical comparisons were conducted by using the Student's t test, χ^2 with Yates' continuity correction, the Mann-Whitney U test, and analysis of variance with the Scheffe post hoc multiple comparisons procedure. Normally distributed data are expressed as mean ± SD.

RESULTS

Over the 4-year period, of 370 new patients enrolled in the Lead/Toxicology Program, 50 (14%) were infants. Twenty-seven were girls and 23 were boys. Median age of these patients was 11 months (range 1 through 12 months). Six infants aged 1 through 7 months were identified after their older siblings were found to have plumbism. Socioeconomic status as indicated by hospital payer classification revealed 33 patients (66%) with private insurance and no stated reliance on public welfare. Only 26% received Medicaid or other public assistance.

No patients had clinical signs of lead intoxication. Sixteen infants (32%) were ambulatory at the time lead poisoning was diagnosed. Twelve infants (24%) had a history of pica (excessive oral habits which included repeated ingestion of nonfood objects).

Mean peak whole blood lead level was 39.0 ± 11.4 μg/dL. Thirteen infants had a peak lead level >50.0 μg/dL. Mean peak erythrocyte protoporphyrin level was 111.8 ± 90.9 μg/dL.

Iron status was assessed by the combination of hemoglobin level, hematocrit, mean corpuscular volume, serum iron levels, TIBC, and serum ferritin levels. Twenty-five patients (50%) had hemoglobin levels of <11.5 g/dL, 28 (56%) had hematocrit of <34%, and 14 (32%) patients had a serum iron-TIBC ratio of <16%. Serum ferritin level was depressed in 20 (40%) patients based on age-specific normal values for The Children's Hospital. Girls had a significantly higher hemoglobin level than boys (11.6 g/dL vs 11.1 g/dL, $P = .04$).

Five distinct origins of lead intoxication were identified: household renovation, ingestion of paint chips, formula preparation, dust importation, and congenital (Table 1).

Twenty cases occurred as a result of household renovation. Renovation was invariably done without knowledge of the lead content of the house; a parent was usually the renovator. In the two cases in which paint was removed with a heat gun, all family members including both parents and siblings were tested and found to have increased lead levels (range 18 to 60 μg/dL).

Ten cases occurred as a result of pica. Seven of these cases were notable for the witnessed ingestion of paint chips. All 10 children in this group were walking before the age of 10 months. However, the abdominal radiograph identified radiopaque material in only two infants at the time of evaluation.

Nine cases of plumbism were traced to the preparation of powdered or concentrated infant formula with lead-contaminated water (Table 2). Three distinct patterns of hazardous formula reconstitution were identified: (1) use of contaminated tap water which had been boiled for 10 to 20 minutes (n = 5); (2) use of either tap or spring water which was boiled in a leaded vessel (n = 3); and (3) use of contaminated first-draw, unboiled morning water to make the day's supply of formula (n = 1). In seven of these cases, exposure was confirmed by analysis of the water used to prepare the formula and the exclusion of other available lead sources. Water lead concentrations as high as 200 000 parts per billion were found in the confirmed cases.

When cases were dichotomized into formula-associated cases (9) vs non-formula-associated cases (41), there was no significant difference in peak blood lead level (38.9 vs 39.3 μg/dL), but significantly lower hemoglobin level (10.8 g/dL vs 11.6 g/dL, $P = .02$), hematocrit (32.3% vs 34.2%, $P = .05$), serum iron-TIBC ratio (0.156 vs 0.294, $P = .008$), and ferritin level (20.5 ng/mL vs 36.3 ng/mL, $P = .011$) were found in children with lead intoxication from contaminated formula. This difference persisted when all discrete routes of exposure were compared with formula-associated cases by analysis of variance.

One case each of plumbism occurred as a result of dust importation by a parent who worked extensively with lead and by placental passage of maternal lead. In the case of dust importation, the father, a private contractor, was found to have a blood lead level of 70 μg/dL after lead intoxication was identified in the infant. The case of congenital lead intoxication occurred in a newborn whose adolescent mother devel-

TABLE 1. Identifiable Sources of Lead Poisoning

Source	No. (%)
Household renovation	29 (49)
Paint chip ingestion	10 (24)
Formula preparation	9 (24)
Work clothing	1 (2)
Congenital	1 (2)
Total	41 (100)

TABLE 2. Cases Resulting From Formula Preparation With Lead-Contaminated Water

Case	Age, mo	Confirmed	Peak PbB,* μg/dL	Lead Source	[Pb], ppb
1	4	–	31	Boiled water	
2	4	–	30	Boiled water	
3	9	+	21	Boiled water	142
4	9	+	47	Boiled water	1.0×10^3
5	9	+	41	Boiled water	117
6	9	+	55	Lead vessel	3.5×10^3
7	12	+	48	Lead vessel	1.7×10^3
8	12	+	57	Lead vessel†	2.0×10^5
9	12	+	40	Morning water‡	150

* PbB, blood lead concentration.
† Formula prepared with spring water only.
‡ Previously reported elsewhere.[19]

oped lead intoxication at age 2 but was never fully treated. The infant's blood lead level, obtained at the age of 1 month, was 31 μg/dL; the simultaneous maternal lead level was 40 μg/dL.

Among the 47 toddlers selected for comparisons, mean age was 23.8 ± 3.5 months. Peak lead level was 42.2 ± 16.8 μg/dL (P = not significant compared with infant lead levels). Compared with the infant population, there were no significant differences in distribution of payer status, hemogram, or iron indices. However, a higher rate of pica was reported in the older group (Table 3). The origins of lead intoxication in the older group were paint chip ingestion by history in 41 (87%), household renovation in 2 (4%), and unknown in 4 (9%). This distribution differed significantly from that in the younger infants ($P < .0001$).

DISCUSSION

The findings in this study suggest that the origins of lead intoxication in the first year of life differ considerably from those found in toddlers. These differences have important implications both for the identification of lead intoxication and appropriate environmental inspection for this age group.

The most common source of plumbism in infancy was found to be household renovation (49% of identifiable cases). Home renovation, when not being done for the purpose of deleading, has been identified as a significant predictor of elevated lead levels in children.[7,9] Use of heat guns and sanding create particularly toxic lead fumes or lead dust which are efficiently absorbed after ingestion and/or inhalation.[10]

Pica, long considered the most common mechanism of lead intoxication in children, accounted for only 24% of infant cases where the source could be identified. This is not surprising when one considers that the infant who is not yet ambulating and under close supervision has limited opportunities for the ingestion of paint chips. This low frequency stood in contrast to the 87% frequency found among the toddlers who attended our program.

TABLE 3. Origins of Lead Intoxication: Infants vs Toddlers*

Source	Infants, No. (%)	Toddlers, No. (%)
Renovation	20 (40)	2 (4)
Paint chip ingestion	10 (20)	41 (87)
Formula preparation	9 (18)	0
Work clothing	1 (2)	0
Congenital	1 (2)	0
Unknown	9 (18)	4 (9)

* $P < .0001$, Mann-Whitney.

The frequency of lead intoxication traced directly to formula preparation practices was surprising. A 10th infant has been identified since the completion of this study. The use of lead pipes for plumbing was standard until 1920, and lead-based solder was widely used in plumbing until 1984; these products were not banned from the plumbing industry until 1986.[5] Their ubiquity has created an almost inescapable lead hazard in our water supply. An estimated 10 400 000 children are exposed to significant amounts of lead through drinking water and 241 000 children younger than 6 years have lead levels greater than 15 μg/dL as a result of drinking such lead-contaminated water.[5,11–13] Recent actions by the Environmental Protection Agency to reduce the acceptable level of waterborne lead from 50 to 15 parts per billion have attempted to address this widespread problem.

Eight of the nine cases involved the practice of adding boiled water to powdered or concentrated formula. Powdered and concentrated infant formulas do recommend boiling water for 5 minutes, for the purpose of sterilization, before adding it to reconstitute these preparations (personal communication, Ross Laboratories, Columbus, OH). Excessive boiling, however, increases the lead concentration of tap water, amplifying the risk of lead intoxication and exposing the infants to substantial quantities of lead with every formula feeding.

Ceramic and pewter kitchenware are well-known sources of leachable lead.[6,14] However, in the three cases associated with lead-based kettles, the instruments were an antique copper-covered lead vessel, a cooking vessel brought from the Middle East, and a pot manufactured in the United States. The importation of leaded cooking vessels by immigrants may represent another unappreciated lead hazard.

The difference in iron status between the formula- and non-formula-poisoned children is of interest. The most plausible explanation would be that infants with formula-associated plumbism had inadequate iron intake throughout their period of lead exposure. The retrospective nature of this study did not permit complete details on use of normal- vs low-iron formula in these infants; in fact, when details were available,

a history of combined formula use was often present. However, because iron deficiency is known to increase gastrointestinal lead absorption, the presence of this nutritional deficiency would have been a significant contributor to the development of lead intoxication.

Even after detailed history and standard home inspection were conducted, the source of lead was unclear in 9 infants and 4 toddlers. There are several possible explanations for the inability to determine origin in these cases. One is that the Massachusetts standard home inspection, which required only paint analysis by x-ray fluorescence (a method with significant imprecision), may have missed other lead hazards. Alternatively, these cases may have occurred from outdoor activity with exposure to exterior paint or leaded soil (11 of these 13 cases of lead intoxication were identified between the months of June and September). Plumbism may have also occurred from unwitnessed episodes of pica. Finally, these cases may have been the result of normal oral activities within homes with high levels of lead-based dust; an estimated 34% of a child's typical daily lead dose originates from such dust even in the absence of pica.[15,16]

Little information on the prevalence of lead intoxication in infants is available. In Massachusetts 30 250 infants were screened for plumbism in 1990 (a screening rate of 35% based on the 85 000 births in the state in 1989). Of these, 46 (0.1%) were found to have whole blood lead levels of ≥25 μg/dL (personal communication, M. J. Brown, Massachusetts Department of Public Health). This is in contrast to a 1.1% incidence rate which has been found in 13- through 36-month-old children undergoing lead screening in Massachusetts in 1989.

In both age groups we found a high rate of lead intoxication among children of middle and upper socioeconomic strata. While this prevalence may represent referral patterns specific to our program and is therefore not generalizable, rates of lead intoxication in suburban areas as high as 30% have been reported in previous studies.[17,18]

These data support recent recommendations to initiate lead screening in children at 6 months. Highest priority should be given to children living in older, dilapidated housing, those whose homes have recently undergone renovation, and those who share environmental contacts with a child known to have plumbism. These children should receive venous lead measurements rather than erythrocyte protoporphyrin screening, given the insensitivity of erythrocyte protoporphyrin in detecting low-level lead exposures.

Finally, our findings suggest the need for systematic evaluation of potentially hazardous formula preparation practices. In addition to discussing common lead sources, child care providers should provide education on safe methods of formula preparation if all significant sources of lead are to be identified and avoided.

ACKNOWLEDGMENT

We are indebted to Masayuki Sakamoto of Clinical Laboratories, Children's Hospital, for analysis of water samples.

REFERENCES

1. Needleman HL, Gunnoe C, Leviton A, et al. Deficits in psychologic and classroom performance of children with elevated dentine lead levels. *N Engl J Med.* 1979;300:689–695
2. Needleman HL, Schell A, Bellinger D, Leviton A, Allred EN. The long-term effects of exposure to low doses of lead in childhood: an 11-year follow-up report. *N Engl J Med.* 1990;322:83–88
3. Bellinger D, Leviton A, Waternaux C, Needleman H, Rabinowitz M. Longitudinal analyses of prenatal and postnatal lead exposure and early cognitive development. *N Engl J Med.* 1987;316:1037–1043
4. McMichael AJ, Baghurst PA, Wigg NR, Vimpani GV, Robertson EF, Roberts RJ. Port Pirie cohort study: environmental exposure to lead and children's abilities at the age of four years. *N Engl J Med.* 1988;319:468–475
5. Agency for Toxic Substances and Disease Registry. *Childhood Lead Poisoning-United States: Report to the Congress.* Atlanta, GA: Centers for Disease Control; 1988
6. American Academy of Pediatrics, Committee on Environmental Hazards, Committee on Accident and Poison Prevention. Statement on childhood lead poisoning. *Pediatrics.* 1987;79:457–465
7. Bellinger D, Leviton A, Rabinowitz M, Needleman H, Waternaux C. Correlates of low-level lead exposure in urban children at 2 years of age. *Pediatrics.* 1986;77:826–833
8. Mahaffey K, Annest JL, Roberts J, Murphy RS. National estimates of blood lead levels: United States, 1976–1980. Association with selected demographics and socioeconomic factors. *N Engl J Med.* 1982;307:573–579
9. Rabinowitz M, Leviton A, Bellinger D. Home refinishing, lead paint, and infant blood lead levels. *Am J Public Health.* 1985;75:403–404
10. Fischbein A, Anderson KE, Sassa S, et al. Lead poisoning from 'do-it-yourself' heat guns for removing lead-based paint: report of two cases. *Environ Res.* 1981;24:425–431
11. Houk VN, Ing RT, Falk H. Assessing lead exposure from drinking water. *Am J Public Health.* 1989;79:823–824
12. Rabinowitz M, Needleman H, Burley M, Finch H, Rees J. Lead in umbilical blood, indoor air, tap water, and gasoline in Boston. *Arch Environ Health.* 1984;39:299–301
13. Bander LK, Morgan KG, Zabik ME. Dietary lead intake of preschool children. *Am J Public Health.* 1983;73:789–794
14. Lead in ceramic ware. *FDA Drug Bull.* Nov 1988
15. Sayre JW, Charney E, Vostal J, Pless IB. House and hand dust as a potential source of childhood lead exposure. *AJDC.* 1974;127:167–170
16. Bushnell PJ, Jaeger RJ. Hazards to health from environmental lead exposure: a review of recent literature. *Vet Hum Toxicol.* 1986;28:255–261
17. Linakis JG, Shannon MW. Plumbism in the children of young professionals: yuppie lead. *Vet Hum Toxicol.* 1989;31:341
18. Brown MJ, DeGiacomo JM, Gallagher G, et al. Lead poisoning in children of different ages. *N Engl J Med.* 1990;323:135–136
19. Shannon MW, Graef JW. Lead intoxication from preparation of formula with lead-contaminated water. *Clin Pediatr (Phila).* 1989;38:380–382