

Development of a Screening Tool for Prediction of Children at Risk for Lead Exposure in a Midwestern Clinical Setting

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ABSTRACT. *Objective.* Universal screening for childhood lead poisoning is becoming quite common, with many states having legislation requiring screening. We set out to determine whether a questionnaire could be used to identify children at risk for exposure to lead to determine whether selective screening of those at risk was possible.

Methods. Parents of 370 children 12 to 36 months of age having well-child examinations completed a questionnaire and their children were screened by a finger-stick capillary blood lead test at two clinics.

Results. Of patients from clinic A, 5.4% had lead levels ≥ 10 $\mu\text{g}/\text{dL}$ compared with 16.8% of those from clinic B ($P < .001$). This difference between clinics could not be explained by the demographic characteristics of the patients or by differences in their potential exposures to lead. We evaluated the five questions suggested by Centers for Disease Control and Prevention for anticipatory guidance for their ability to identify children with elevated blood lead levels. In clinic A, this instrument had a sensitivity of 76.9% and a negative predictive value of 96.5%. In clinic B, it had a sensitivity of 63.6% and a negative predictive value of 81.4%. Based on an assessment of significant items from a large questionnaire, we determined five questions that were the best predictors of risk. On the basis of this risk assessment, 100% of the children from clinic A with elevated lead levels and 90.9% of the children from clinic B with elevated lead levels were classified as being at "high risk." Had this risk assessment been used as an initial screen in this sample, 40% of the patients from clinic A and 37% of the patients from clinic B would not have been screened with a blood lead test, because they were classified as being at "low risk."

Conclusions. Results of this study suggest that there is great variability in the prevalence of elevated lead levels and potential risks between clinics within a fairly homogeneous community; however, selective screening with a community-specific questionnaire may be feasible if the prevalence is low and the risks to the population are known. *Pediatrics* 1994;93:183-187; *lead, screening, risk assessment.*

ABBREVIATION. CDC, Centers for Disease Control and Prevention.

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Although patterns of childhood lead poisoning have changed substantially in the United States in the past 15 years, lead poisoning remains a significant public health concern.¹⁻⁷ According to a recent estimate, 15% of all children in the United States may have blood lead levels ≥ 10 $\mu\text{g}/\text{dL}$, which may be high enough to cause neurobehavioral and other adverse health effects.⁸ The Centers for Disease Control and Prevention (CDC) has recommended that anticipatory guidance and assessment of the risk of lead poisoning should be part of routine pediatric care.⁷ Current CDC guidelines recommend that pediatric health care providers should discuss childhood lead poisoning with the child's parents and assess the child's risk for high-dose exposure starting at 6 months of age and at each regular visit thereafter. These guidelines recommend universal screening in all communities except those in which the prevalence or number of children with elevated blood lead levels is low.

Universal screening is not mandated in every state, but by 1991, 16 states had lead statutes with screening provisions, and an additional 19 had lead statutes with no screening provisions.⁹ Some proponents of universal screening laws suggest that lead screening meets all the criteria for suggested population-based screening and that universal screening would be cost-effective if the prevalence of lead poisoning in the population is as low as 0.1%.¹⁰

Opponents of universal screening^{11,12} argue that the prevalence of elevated blood lead levels is low, that the association between low lead levels and "clinically significant, detrimental, neurobehavioral affects ... is still debated,"¹¹ and that there is no effective therapy for children with low lead levels.

The CDC guidelines include five questions that may be used to assess risk and thus to determine the frequency of screening necessary. These questions were not intended for selective screening of children at high risk for elevated lead levels; however, if a reliable questionnaire was available to determine a child's risk and if screening could be conducted on the basis of this risk, selective screening could be more cost-effective than universal screening in an area of low prevalence. A questionnaire that assesses risks specific to the community would be most helpful to health practitioners.

With this in mind, we set out to evaluate the five questions in the CDC guidelines and to develop a community-specific questionnaire that could be used to determine whether a patient was at increased risk

for lead exposure and thus in need of further evaluation with a blood lead test. We also hoped to determine the prevalence of elevated blood lead levels in the clinical setting and the magnitude of certain exposures or "high-risk activities" within this setting. This information could then be used to help direct a population-specific screening and educational effort.

METHODS

From May 4 through September 4, 1992, we recruited children between the ages of 12 and 36 months who received routine well-child care at one of the two major health care organizations serving La Crosse, WI (county population 97 904). These two organizations operate eight of the nine health care sites serving children in the community. One of the organizations (clinic A) had three pediatric or family practice sites associated with it; the other (clinic B) had five pediatric or family practice sites associated with it.

By conducting weekly reviews of appointment schedules at each of the eight clinics, we selected a proportional number of potential study subjects from each site based on the total number of well-child examinations per year at each site. Potential subjects were selected from the schedules either by selecting every *n*th patient, where *n* varied by clinic depending on the number of well-child examinations, or by choosing appointments within time blocks convenient for the purpose of enrollment. Only one child per household was included in the study; if multiple children were scheduled for an examination, the oldest within the age criteria was selected. Potential subjects were unaware of their selection before arriving at the clinic for their scheduled appointment. Parents of the selected children were then informed of the study and asked whether they wished to participate. After providing informed consent, parents completed a six-page, self-administered questionnaire before the child's well-child examination. After the examination, we obtained a fingerstick blood sample using the technique recommended by CDC⁷ to measure a child's blood lead level. All parents of children enrolled in the study received a letter with the child's blood lead result and information on any necessary follow-up. Reported here are initial fingerstick results only, without venous blood test confirmation.

The questionnaire asked for information about the age and condition of the child's home, the child's possible exposure to a variety of lead sources, and basic demographics. In addition, it included questions suggested by CDC for assessing lead exposure risk in children⁷ and was available both in English and Hmong, the two predominant languages of the patient population.

All data were entered into a data base and analyzed with SAS statistical software.¹³ The relationship between the prevalence of elevated lead levels (≥ 10 $\mu\text{g}/\text{dL}$) and responses to individual questions was examined using Yate's continuity-adjusted χ^2 or Fisher's exact test. Results were considered to be statistically significant at $P < .05$. A prevalence ratio was calculated for each item. Using the questions found to be significantly associated with elevated blood lead levels in the univariate analysis, we then selected five factors as the best risk assessment combination for this community. We determined the sensitivity, specificity and predictive value of this best community questionnaire and the five CDC questions.

RESULTS

Of 565 children selected from appointment schedules, we recruited parents of 454; 370 (81%) of those recruited agreed to participate in the study. A total of 111 were not recruited because they did not keep their appointment or were missed at the clinic visit. The characteristics of the study population and of the nonparticipants are shown in Table 1. The participants and nonparticipants were fairly similar, although the participants tended to be a bit younger. Furthermore, there were no statistically significant differences in demographic characteristics between the participants and the 84 children whose parents were recruited but refused to participate.

Overall, 35 (9.5%) of the children screened in this study had capillary blood lead levels ≥ 10 $\mu\text{g}/\text{dL}$:

TABLE 1. Demographic Characteristics of Lead Study Participants and Nonparticipants*

Variable	Participants (n = 370)	Nonparticipants (n = 195)
Gender		
Male	51.1	52.3
Female	48.9	47.7
Age		
12-16 mo	36.5	29.2
17-25 mo	54.6	55.4†
26-36 mo	8.9	15.4
Ethnicity		
White	97.8	97.4
Nonwhite	2.2	2.6
Home address		
Within city of La Crosse	42.4	47.2
Within immediate area of La Crosse	33.4	30.8
Outside greater La Crosse	24.1	22.1
Location screened		
Clinic A	64.6	60.0
Clinic B	35.4	40.0
Reason not included		
Refused (n = 84)		43.0
Did not keep appointment (n = 67)		34.4
Missed enrollment (n = 44)		22.6

* Values given are percentages.

† Differences significant at $P < .05$.

5.4% from clinic A and 16.8% from clinic B ($P < .001$). The 13 elevated levels from clinic A ranged from 10 $\mu\text{g}/\text{dL}$ to 30 $\mu\text{g}/\text{dL}$, with a median of 13 $\mu\text{g}/\text{dL}$. The 22 elevated levels from clinic B ranged from 10 $\mu\text{g}/\text{dL}$ to 35 $\mu\text{g}/\text{dL}$, with a median of 16 $\mu\text{g}/\text{dL}$. This difference in prevalence of elevated lead levels between the two clinics was not explained by any differences in demographics or by responses to the questions found to be independently associated with elevated levels. Because of this unexplained difference between the two clinics, the results are presented separately for each clinic.

Clinic A

The relationship between blood lead levels and various demographic characteristics is shown in Table 2. For children from clinic A, we found no significant relationship between the prevalence of elevated levels and any of the demographic characteristics. All the elevated blood lead levels were found in white children, but there were few children of other racial groups in the sample (n = 6). The rates of elevated lead levels for children living within La Crosse were similar to those of children living in rural areas.

The relationship between the characteristics of the patients' housing and the prevalence of elevated blood lead levels is shown in Table 3. Because the percentage of children with elevated blood lead levels was similar among those whose parents indicated they lived in houses more than 50 years old (25% overall) and among those whose parents were unaware of the age of the building (22% overall), the two categories were combined. In clinic A, children whose parents reported that they lived in a house more than 50 years old or were not aware of the age were at a 10.2 times higher risk of having an elevated lead level than were those who lived in a house less than 50 years old

TABLE 2. Percentage of Children with Elevated Blood Lead Levels ($\geq 10 \mu\text{g/dL}$) by Demographic Characteristics*

Variable	Clinic A (n = 239)	Clinic B (n = 131)
Overall prevalence	5.4	16.8
Gender		
Male	4.6 (5/109)	16.3 (13/80)
Female	6.2 (8/130)	17.7 (9/51)
Age		
12–16 mo	6.6 (6/91)	15.9 (7/37)
17–25 mo	5.3 (7/131)	14.1 (10/71)
26–36 mo	0.0 (0/17)	31.3 (5/16)
Ethnicity		
White	5.6 (13/233)	17.1 (22/129)
Nonwhite	0.0 (0/6)	0.0 (0/2)
Payment method		
Private insurance	4.8 (9/188)	11.7 (12/103)†
No private insurance (MA)	7.8 (4/51)	35.7 (10/28)
Home address		
Within La Crosse	6.5 (6/93)	23.4 (15/64)†
Within immediate area of La Crosse	3.5 (3/85)	2.6 (1/39)
Outside greater area	6.6 (4/61)	21.4 (6/28)

* Values given are percentages. MA = medical assistance.

† Differences significant at $P < .05$.

($P = .001$). Children whose parents reported peeling paint on the inside of the house were at a 3.9 times increased risk of having an elevated blood lead level ($P = .019$).

A variety of other possible risks were evaluated as shown in Table 4. Of these, only the prevalence ratio for a child having chewed on furniture was statistically significant. Ten percent of clinic A's patients whose parents recalled this had elevated blood lead levels compared with 3% of those who did not. Additional risk questions that we considered but found not to be significant included the child's having been given folk remedies; the child's history of iron, calcium, or zinc deficiency; the child's attendance at a day care facility, and if so, the age and type of building; the type of plumbing in the child's house; a household practice of refrigerating opened canned foods; consumption of imported canned food; presence of antique painted furniture or toys in the home; the age and marital status of the parent; and a history of remodeling of the home in the previous 2 years.

Clinic B

The relationship between blood lead levels and various demographic characteristics for patients in clinic B is also shown in Table 2. There was no significant relationship between the prevalence of elevated levels and gender or age, although the highest proportion of elevated blood lead levels in this sample did occur among children 26 to 36 months old. Children whose primary source of payment was Medicaid were 3.1 times as likely to have an elevated blood lead level as those covered by private health insurance ($P = .006$). The prevalence of elevated lead levels was 9.1 times higher among those who lived within the city of La Crosse compared with those in the immediate surrounding area ($P = .001$). The prevalence was also 8.4 times higher among those who lived in rural areas compared with those who lived in the immediate surrounding area ($P = .037$).

TABLE 3. Prevalence Ratio of Elevated Blood Lead Levels ($\geq 10 \mu\text{g/dL}$) by Housing Characteristics

Variable	Prevalence Ratio (P Value)	
	Clinic A	Clinic B
Age of child's home		
≤ 50 y	...*	...
>50 y/unknown	10.17 (0.001)†	3.71 (0.001)†
Peeling paint on exterior		
No peeling paint	...	...
Peeling paint	2.56 (0.141)	1.98 (0.137)
Chalking on exterior		
No	...	...
Yes	1.63 (0.854)	1.57 (0.695)
Remodeling projects on exterior		
No	...	...
Yes	2.55 (0.163)	0.72 (0.698)
Peeling paint on interior		
No peeling paint	...	...
Peeling paint	3.91 (0.019)†	3.21 (0.004)†
Broken plaster inside		
No	...	...
Yes	1.41 (0.872)	2.75 (0.028)†
Remodeling projects on interior		
No	...	...
Yes	1.46 (0.673)	0.71 (0.556)
Live on/near a farm		
No	...	...
Yes	2.40 (0.180)	0.72 (0.650)
Type of home		
Single dwelling	...	...
Multiple housing	0.00 (0.233)	1.51 (0.507)

* Reference level for computation of prevalence ratio.

† Differences significant at $P < .05$.

The relationship between characteristics of the patient's housing and prevalence of elevated lead levels is shown in Table 3. As in clinic A, the prevalence of elevated lead levels was significantly associated with living in a house greater than 50 years old or of unknown age and with having peeling paint on the interior. Among clinic B's patients, reports of broken plaster were also associated with the prevalence of elevated lead levels.

Of the questions not related to housing, parents' occupation and smoking status were significantly related to the prevalence of elevated lead levels in clinic B's patients. Reported occupations were coded into one of three categories of risk on the basis of an assumed likelihood of job-related lead exposure: "low risk," "possible risk," and "probable risk." The proportion of children with elevated blood lead levels increased from 11% in the low-risk category, to 21% in the possible-risk category, and 28% in the probable-risk occupational category, although this increase was not statistically significant. A child with a parent in a probable-risk category was 2.4 times as likely to have an elevated blood lead level than a child with a parent in a low-risk category ($P = .044$). Children who lived with at least one smoker were 2.6 times more likely to have elevated blood lead levels than children who lived with nonsmokers ($P = .013$).

Evaluation of Screening Tools

In an attempt to assign risk for screening purposes, we assessed several questions in combination. We first evaluated the five risk questions recommended by CDC.⁷ A child was considered to be at high risk if

TABLE 4. Prevalence Ratio of Elevated Blood Lead Levels (≥ 10 $\mu\text{g}/\text{dL}$) by Miscellaneous Exposures

Variable	Prevalence Ratio (<i>P</i> Value)	
	Clinic A	Clinic B
Parent's occupation		
Probable high risk	2.55 (0.244)	2.39 (0.044)*
Possible high risk	1.35 (0.980)	1.81 (0.413)
Probable low risk	... †	...
Parent's smoking status		
Lives with a smoker	1.31 (0.626)	2.60 (0.013)*
No smoker in home	...	...
Use hot water for cooking		
No	...	...
Yes	1.02 (0.975)	0.72 (0.432)
Witnessed child chewing on furniture		
No	...	...
Yes	3.24 (0.025)*	0.86 (0.912)
Either parent makes stained glass		
No	...	...
Yes	3.90 (0.650)	1.51 (0.525)
Cook or store food in pottery		
No	...	...
Yes	1.02 (0.999)	1.20 (0.999)

* Differences significant at $P < .05$.

† Reference level for computation of prevalence ratio.

the parent answered "yes" to any one of the five questions. When this method was used in clinic A, only 10 (76.9%) of the 13 children with elevated lead levels were accurately assigned to the "high-risk" category (Table 5). The negative predictive value was 96.5%. In clinic B, only 14 (63.6%) of the 22 children with elevated lead levels were accurately assigned to the "high-risk" category. In clinic B, the negative predictive value of the five CDC questions was 81.4%.

We then tested the eight risk questions found to be significantly associated with the prevalence of elevated lead levels and selected five questions that maximized the sensitivity and negative predictive value in this study group. The addition of the other three significant items did not affect the performance of the questionnaire. The five items on this best community questionnaire were: enrolled in Medicaid, living in a house >50 years old or unknown age, having peeling paint inside the house, having any broken plaster inside the house, and living with a person who smokes. Using a parent's report of any one of these questions to determine that a child was at high risk, 100% of the children from clinic A with elevated blood lead levels were accurately assigned to the "high-risk" category (Table 5). The negative predictive value of this risk assessment was 100%. If this risk assessment had been used to select children for blood lead tests, 39.7% of the patients from clinic A would have been assigned to the "low-risk" category and would not have been screened. Using the same questions to assign risk to patients in clinic B, 90.9% of the 22 children with elevated blood lead levels were accurately assigned to the "high-risk" category. Nine percent of children with elevated lead levels would have been classified as at "low risk" by this assessment tool if it had been used to select children for blood lead tests, and 37.4% of the patients would not have been screened.

TABLE 5. Performance Characteristics of the Centers for Disease Control and Prevention Questionnaire (CDC-Q) and of the Best Community Questionnaire (Best-CQ) to Screen Children for Lead Poisoning*

	Clinic A (n = 239) 5.4%†		Clinic B (n = 131) 16.8%†	
	CDC-Q‡	Best-CQ§	CDC-Q‡	Best-CQ§
Percent classified "high risk"	64.0	60.3	67.2	62.6
Sensitivity	76.9	100.0	63.6	90.9
Specificity	36.7	42.0	32.1	43.1
Positive predictive value	6.5	9.0	15.9	24.4
Negative predictive value	96.5	100.0	81.4	95.9

* Values given are percentages.

† Prevalence of children with elevated blood lead levels.

‡ CDC Questionnaire: Yes to any one of the following: Does your child:

- Live in or regularly visit a house with peeling or chipping paint built before 1960? This could include a day care center, preschool, the home of a babysitter or a relative.
- Live in or regularly visit a house built before 1960 with recent, ongoing, or planned renovation or remodeling?
- Have a brother or sister, housemate, or playmate being observed or treated for lead poisoning (that is blood lead ≥ 15 $\mu\text{g}/\text{dL}$)?
- Live with an adult whose job or hobby involves exposure to lead?
- Live near an active lead smelter, battery recycling plant, or other industry likely to release lead?

§ Best Community Questionnaire: Yes to any one of the following:

- Are you on medical assistance?
- Do you live in a house that is 50 years old or older? (or unknown age)
- Is there any peeling paint or paint chips on the inside of the home in which your child lives?
- Is there any broken plaster on the walls inside the building or house in which your child lives?
- Is there anyone in your child's home that smokes cigarettes?

DISCUSSION

The results of this study suggest that a community-specific risk questionnaire may be useful for assessing risk where the prevalence of elevated blood lead levels is low and the sources of exposure are fairly well understood. Using the best community questionnaire we would predict that nearly 40% of all patients would have been considered low risk, with a prevalence of elevated lead levels in this low-risk group of only 1.4%. By asking five questions about the patient's environment, the health practitioner may be able to predict whether a child is at risk for elevated lead levels. We found that asking parents these questions opened a dialogue between the parent and the health practitioner about lead.

The percentage of children with elevated blood lead levels ≥ 10 $\mu\text{g}/\text{dL}$ in this study was much lower than what was expected. Because 34.8% of the houses in the community were built before 1950,¹⁴ we expected the percentage of children with elevated blood lead levels to be much closer to the estimated national average of 15%.⁸ Because of the low prevalence of elevated lead levels, there might not have been sufficient power to adequately evaluate the predictive ability of some of the items on this questionnaire. A follow-up study is currently underway to further assess the predictive ability of the best community questionnaire in a new sample of patients.

The prevalence of elevated lead levels was assessed using fingerstick samples without venous confirmation. Although contamination of the fingerstick samples could result in falsely elevated lead levels, all samples were obtained following strict protocols to minimize such contamination. Whereas some misclassification as to actual blood lead levels may occur from using a fingerstick blood sample, the results presented here provide an unbiased estimate of the performance of the risk assessment questions with reference to an elevated fingerstick level. Fingerstick sampling is the screening method of choice for many pediatricians.

We found that parent's occupation was a good predictor of increased risk of elevated lead levels among clinic B's patients. A health practitioner would have difficulty coding parental occupation and parents may not be aware of an occupational exposure to lead. This limits the ability to use such an item to assess patients' risk.

Results of previous studies^{15,16} have indicated that children of parents who smoke are at increased risk for elevated blood lead levels. In this study, among clinic B's patients, children who lived with at least one adult smoker were found to have a higher prevalence of elevated blood lead levels than children of non-smokers. The usefulness of a question on parental smoking and prediction of a child's risk for lead exposure may need to be evaluated in other populations as well.

The results of this study revealed some interesting differences between clinics. The difference in prevalence of elevated lead levels may have been due to unmeasured differences in the socioeconomic status of the patients, or in a difference in the patients' housing condition. Our only measure of socioeconomic status was payment method, which may not have been a sensitive enough measure to effectively demonstrate a difference between clinics. A similar percentage of patients from both clinics were enrolled in Medicaid; however, 35.7% of the Medicaid patients from clinic B had elevated blood lead levels compared with only 7.8% of those from clinic A ($P = .004$). Although the percentage of children living in houses more than 50 years old was similar for patients from clinic A (18.4%) and clinic B (18.3%), the condition and upkeep of the house may have been worse among patients from clinic B. Only 17% of patients from clinic A living in these older houses had elevated levels, compared with 37.5% of those from clinic B ($P < .001$). Results of an analysis of patients' addresses suggested that clinic B tended to draw more patients from the more deteriorated parts of the community. Because of the small number of elevated levels overall, we could not determine whether this tendency was the major reason for the difference between clinics in rates of elevated levels.

The results of this study suggest there may be great variability in the prevalence of elevated blood lead levels, and potential exposures to lead between health care sites within a relatively homogeneous community. The five questions suggested by CDC for the purpose of assessing risk had limited sensitivity and negative predictive value in this community. After

extensive analysis of responses obtained in practice settings, we were able to derive a community-specific questionnaire with improved performance in assessing risk. The CDC recommends screening all children in a community with a blood lead test unless it has been shown that the prevalence of elevated blood lead levels is low. In communities shown to have a low prevalence, community-specific questionnaires similar to ours might be derived and used to selectively screen children for blood lead testing. Selective screening using a well-tested questionnaire with high sensitivity and high negative predictive value could be especially useful in low-prevalence areas where there are insufficient resources to perform blood lead testing on all children. However, our results indicate that the use of a general questionnaire that has not been tested in a given community or practice site may lead to substantial misclassification of lead exposure risk.

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