Targeting Lead Screening: The Ohio Lead Risk Score

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ABSTRACT. *Objective.* **Annual blood lead (BPb) screening is recommended for children ≤2 years of age residing in high-risk areas. Strategies for identifying these areas exist but lack specificity. We sought to develop an efficient method for identifying risk factors for undue lead exposure in children by using community variables.**

Design. **Logistic regression for model development in one half of the sample followed by validation of the model in the remaining half.**

Methods. **The association between selected census tract characteristics from 19 Ohio counties and the BPb test results of children living in those census tracts was evaluated. The dependent variable, high-risk status, was defined as a census tract with ≥12% of BPb test results ≥10 μg/dL.**

Results. **Data from 897 census tracts were available. Higher risk for lead toxicity existed in areas where: 1) ≥55% of houses were built before 1950 (adjusted odds ratio [AOR]: 10.9 [6.1,19.6]); 2) ≥35% of residents were black (AOR: 3.5 [2.0,6.3]); 3) ≥35% of residents had less than a high school education (AOR: 6.1 [3.6,10.4]); and 4) ≥50% of housing units were renter-occupied (AOR: 3.6 [2.1,6.2]). Receiver operator characteristic (ROC) curves demonstrated no significant differences after applying the model in a second dataset.**

Conclusions. **Several community characteristics predict risk for lead toxicity in children and may provide a useful approach to focus lead screening, especially in communities where public health resources are limited. The approach described here may also prove helpful in identifying factors within a community associated with other environmental public health hazards for children.** ***Pediatrics*** **2000;106(5). URL: http://www.pediatrics.org/cgi/content/full/106/5/e69;** ***lead screening, predictive index, public health, environmental health.***

ABBREVIATIONS. BPb, blood lead; CDC, Centers for Disease Control and Prevention; ODH, Ohio Department of Health; AOR, adjusted odds ratio; ROC, receiver operator characteristic.

The prevalence of elevated blood lead (BPb) levels in children 1 to 5 years of age has declined remarkably over the last 25 years. In 1976 an estimated 88% of those tested had BPb levels ≥10 μg/dL. In 1991 the Centers for Disease Control and Prevention (CDC) recommended that all children between 1 and 6 years of age undergo annual BPb testing, while those living in high-risk areas should be tested every 6 months.[1] By 1994 the percentage of those with elevated BPb levels had fallen to 4.4%.[2–4] As a result of this dramatic decline and because of mounting concerns over the costs of screening programs, the CDC shifted their approach from universal screening to targeted screening.

The most recent CDC guidelines, using a 2-pronged approach, recommend concentrating BPb testing in areas with a high prevalence of previously abnormal test results or in areas where the density of homes built before 1950 was high.[5] Children targeted for screening are those living in zip codes in which ≥12% of children already tested have BPb levels ≥10 μg/dL, or in the absence of such data, those living in an area where >27% of homes (the national average) were built before 1950. In areas not meeting these criteria, the CDC currently recommends that lead screening be accomplished using a questionnaire on potential sources of lead exposure in the home and community.[5] Children living in low-risk areas are usually referred for BPb testing if parents answer yes to 1 or more questions on the screening questionnaire.

Some question the cost-effectiveness of the approach outlined by the CDC[6] and recognize that this approach may also have limited applicability in certain areas of the country. State and local public health authorities have, therefore, been urged to identify unique risk factors for childhood lead exposure within their communities and work with pediatricians in the development of local screening policies.[5,7]

Several studies have reported screening strategies using a variety of region-specific environmental or ecologic risk factors.[2,8–11] Examples of such factors include residence in areas with older homes, lower housing values, higher population density, lower percentage of high school graduates, lower rates of owner-occupied housing, large numbers of vacant housing, urban locations, and a higher density of immigrants. Most of these characteristics, obtained through the Bureau of the Census, reflect a common factor associated with older housing: economic disadvantage. One of the most obvious limitations in many of these reports is the absence of data on validation, calibration, or discrimination of the models developed. Without these data or data comparing reported models with currently accepted screening

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approaches, it is difficult to judge their public health value in efforts to control childhood lead poisoning.

Based on data from the 1990 census, Ohio ranked the seventh most populous state in the US, yet currently reports the third highest number of children with confirmed BPb levels >25 μg/dL (unpublished data CDC, 1996). Because of this unfortunate distinction, Ohio state law has mandated that all laboratories and physician offices performing BPb tests report their results to the Ohio Department of Health (ODH) Lead Poisoning Prevention Program. In view of a higher density of older housing stock throughout the state, ODH modified the screening guidelines suggested by the CDC by redefining high-risk areas. These included zip code areas in which >27% of the homes were built before 1950 and >15% of children <5 years of age lived below the poverty level. It remains unclear whether this approach represents the most sensible strategy for Ohio, maximizing both sensitivity and specificity.

To determine whether screening strategies recommended by state and federal agencies successfully identified risk for lead poisoning in children, we analyzed lead testing results and ecologic characteristics in a logistic regression model. The model was transformed into an easily applied scoring system, validated, and tested against other screening strategies.

METHODS

Selection of Counties and Census Tracts

To reflect the risk for lead exposure and toxicity among children in a variety of settings, 19 counties located throughout the state of Ohio were selected. Three specific criteria were applied in this selection process: 1) representation of both rural and urban counties (Fig 1); 2) the availability of BPb results from at least 20 children/census tract for at least 2 census tracts within the county; and 3) complete data for each census tract represented in the sample from the 1990 Census of Population and Housing Summary Tape File 3A. In some counties satisfying all 3 criteria, data on testing rates for eligible children varied considerably. To avoid overrepresenting areas in which the testing rate was low, the unit of analysis, therefore, was the census tract rather than the county.

Lead Data and Study Definitions

BPb results were obtained for January 1, 1997 through December 31, 1997 for all children residing in the selected counties who were <6 years of age at the time of testing. The data, resulting from analysis of both capillary and venous blood specimens, were collected by a variety of public and private laboratories and forwarded to a statewide database maintained by ODH. At the time of testing, the primary residence of each child tested was documented. ODH then designates a census tract for the residence of each child to facilitate monitoring and permit regional prevalence estimates. In the event of multiple test results on the same individual, the first value obtained during the study was used. Results for children living in census tracts in which no data from the US Census Bureau existed or results for children for whom census tract assignments could not be made because of incomplete or inaccurate information on location of primary residence were excluded.

Applying nationally used definitions, BPb levels ≥10 μg/dL were considered abnormal. Consistent with current CDC guidelines, high-risk areas for lead exposure in this study were defined as census tracts in which ≥12% of children tested within the tract had elevated BPb levels.[5]

Model Development

After applying the study definitions, associations between risk status and individual census tract characteristics were evaluated. Characteristics considered in this phase of the analysis were identified through a review of previous reports[8–12] and by consensus

Fig 1. Geographic representation of Ohio counties with data used in the development of the Ohio Lead Risk Score.

among the investigators. The mean values for these characteristics were compared between high-risk and low-risk areas in the sample to determine the degree of univariate association. Census tract characteristics associated with high-risk status at $P < .05$ were considered for inclusion in the modeling process.

A 50% random sample of census tracts from each of the 19 counties was obtained to form a dataset from which the model would be derived (derivation dataset). Variables were excluded if colinearity was observed. Stepwise logistic regression[13] was performed using high-risk status (number of abnormal tests/tests performed in children in each census tract) as the dependent variable and select census tract characteristics as the independent variables.

The next phase in creating an easily applied risk-scoring system involved a 2-step approach. First, the continuous values for census tract variables with statistically significant associations ($P < .05$) in the initial model were transformed into binary variables using the midpoint in the mean difference between high-risk and low-risk areas. A value of 0 or 1 was assigned when the mean value for the variable in each census tract fell below or above the midpoint threshold, respectively. These transformed variables were used a second time in creating the final model from the derivation dataset. The resulting adjusted odds ratios (AORs) for each independent variable in this model were rounded to whole integers and a cumulative score for each census tract in the derivation dataset and all remaining census tracts (the validation dataset) was determined. The validity of this scoring system was established by comparing the area under the receiver operator characteristic (ROC) curves for both datasets. The ability of the final model to discriminate high from low-risk census tracts was evaluated using the Somers' *d* test, and calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test statistic.

RESULTS

BPb data from 57 530 children residing in 19 counties (897 census tracts) throughout Ohio were reported to ODH during the study and were available for analysis. Using 1990 census data, 317 753 children 5 years of age and younger resided in these census tracts, resulting in an estimated study testing rate of 18.1%. Of the total number of tests performed during the study, 11 972 (20.8%) were elevated. Four hundred forty-three census tracts (49%) were considered high risk with ≥12% of children tested having BPb results ≥10 μg/dL.

Four hundred fifty-two census tracts were randomly selected from the total sample to form a derivation dataset with the remaining 445 census tracts used to validate the model. These samples did not differ significantly with respect to the following: age of housing stock; percentages of renter-occupied units; population composition by gender, race, or age; percentage of residents having completed high school; poverty indicators (income to poverty level ratio <1.50); and percentage of female heads of households with young children.

The census tract characteristics of areas within the derivation sample with <12% and ≥12% of tested children with significant lead exposure differed significantly in many respects except for the percent of male residents (Table 1). Census tract characteristics with large mean differences (≥10%) in univariate comparisons between high-risk and low-risk areas included: 1) percent of housing units built before 1950; 2) percent of dwellings occupied by a renter; 3) percent of residents with less than high school education; 4) percent of residents with income to poverty level ratio <1.50 (defined as the ratio of income in 1989 to the poverty level defined in the 1990 census); and 5) percent of residents of Black, non-Hispanic ethnicity.

TABLE 1. Differences in the Distribution of Selected Census Tract Characteristics Within the Derivation Sample by Lead Risk Status*

Census Tract Characteristics	Low Risk $n = 234$	High Risk $n = 218$	P Value (2-Tailed)
% housing built before 1950	38.0	70.3	.000
% housing units renter-occupied	40.4	56.2	.000
% residents with <high school education	26.2	41.9	.000
% residents with income to poverty level ratio <1.50	23.6	46.1	.000
% female head of house with children <6 y old	8.3	16.8	.000
% residents <6 y old	9.3	10.7	.000
% male residents	47.2	46.9	.349
% male residents <6 y old	4.8	5.3	.001
% residents of black, non-Hispanic ethnicity	19.5	48.0	.000
% rural†	3.9	.6	.005

* Census tracts in which ≥12% of BPb levels obtained in residents were ≥10 μg/dL were considered high-risk areas for lead exposure and poisoning in children.

† The number of individuals living in a rural area (using farm and nonfarm area designations from the 1990 US Census) divided by the total number of persons living in the census tract.

Census tract characteristics most closely associated with high-risk status in the initial model included: 1) ≥55% of housing within the census tract built before 1950 (AOR: 10.9 [6.1,19.6]); 2) ≥35% of residents of black, non-Hispanic ethnicity (AOR: 3.5 [2.0,6.3]); 3) ≥35% of residents with less than a high school education (AOR: 6.1 [3.6,10.4]); and 4) ≥50% of dwellings occupied by a renter (AOR: 3.6 [2.1,6.2]; Table 2). The Somers' *d* statistic for the logistic regression model was .802, suggesting a modest ability to distinguish between cases in the 2 groups. The Hosmer-Lemeshow goodness-of-fit test statistic for the logistic regression model was 5.8693 ($df = 6$; $P = .438$) indicating a reasonable ability to predict low-risk and high-risk tracts.

The corresponding AOR for each independent variable in the final model was transformed by

TABLE 2. Components of the Ohio Lead Risk Score

Census Tract Characteristics*	AOR (95% Confidence Intervals)	Risk Score
Housing built before 1950	10.9 (6.1, 19.6)	
<55%		0
≥55%		11
Residents of black, non-Hispanic ethnicity	3.5 (2.0, 6.3)	
<35%		0
≥35%		4
Residents with <high school education	6.1 (3.6, 10.4)	
<35%		0
≥35%		6
Housing units renter-occupied	3.6 (2.1, 6.2)	
<50%		0
≥50%		4

* Income to poverty ratio, a measure of socioeconomic status, was dropped from the final model because of colinearity with other variables.

rounding it to the nearest whole integer (Table 2). As an example, a census tract was assigned a score of 11 if the percent of housing within its boundaries was >55% (AOR: 10.9). A cumulative score was determined for each census tract in the derivation and validation datasets using the characteristics identified; the area under the ROC curve for the derivation dataset (.878 [.846,.910]) did not differ significantly with that for the dataset used for validation (.859 [.824,.894]; $P = .44$).

We compared sensitivity, specificity, and positive and negative predictive value of the Ohio Lead Risk Score to the performance of current CDC and ODH screening guidelines in the same population. This scoring system demonstrated greater sensitivity and higher negative predictive value than did the screening approach recommended by ODH and was more specific with higher positive predictive value than was a screening strategy suggested by the CDC (Table 3).

DISCUSSION

Lead, ubiquitous in our environment, comes from a variety of domestic, recreational, and industrial sources.[1] Nationwide initiatives such as removal of lead from gasoline and from solder in tin cans and plumbing systems have resulted in a significant reduction in BPb levels in children over the last 25 years.[2] Although these measures have played a key role in curbing the effects of lead exposure on the health of children, other significant environmental sources of lead exposure remain. In many parts of the United States, lead from paint and paint dust represents the major source of exposure for children, while in other areas mining or other industrial sources serve as the prevalent origin of lead exposure.

The fall in BPb levels among children <6 years of age from 15 μg/dL (1976–1980) to a mean of 2.74 μg/dL (1991–1994)[5] represents a remarkable public health achievement. A result of this success has been a shift in public health policy from a universal to a targeted screening strategy in addressing the potential health effects of lead exposure in children. The means by which public health officials have implemented programs for targeted screening differ throughout the country.

Finding the most effective and efficient approach suited to different areas of the country remains an unmet public health challenge. Targeted screening with an approach based on data collected nationwide represents an appealing, but currently unavailable, solution. In the absence of such data, however, many communities currently perceive the threat of lead poisoning as too small to justify the use of limited public health resources even in areas that may actually be high-risk. Kemper et al[6] evaluated the cost-effectiveness of screening guidelines published by the CDC in 1997. They concluded that only a universal BPb testing approach would be adequately sensitive to identify all children with elevated BPb levels. Although this approach may be most cost-effective in populations with a high prevalence of children with elevated BPb levels, the financial burden of this approach has been viewed as unacceptable in other areas where lead toxicity in children is less common. Kemper et al[6] further suggested that the adopted screening approach be based on an ability to accurately identify high-prevalence areas within a community or state.

Previous studies have consistently demonstrated that houses built before 1950 are important potential reservoirs of lead exposure for children.[2,5,8–10] Although the content of lead in residential paints was substantially reduced in 1971 and was completely eliminated as a result of federal mandates in 1978, deteriorating painted surfaces or recent home renovation remain important factors associated with lead exposure in young children. In contrast, risk for elevated BPb levels among children may be lower in areas where older homes have been better maintained or lead abatement programs have been established.[8,9] However, use of a factor such as older home density in Ohio, a state with an average of 36% of housing units built before 1950, might contribute to an undesirable reduction in positive predictive value and add significantly to the costs of screening programs using this strategy.

Previous studies conducted in Massachusetts, Rhode Island, and Monroe County (Rochester, NY) have suggested alternative screening strategies by using an analytic approach that correlated census tract-based data with BPb levels.[8–10] Although these studies were conducted in areas where the primary source of lead was likely to be paint or paint dust, many of the factors identified overlap some of the factors in the current model. Although our model is based on data from both urban and rural areas

TABLE 3. Comparison of the Ohio Lead Risk Score With State and Federal Screening Strategies

Model	Sensitivity (95% CI)	Specificity (95% CI)	Positive Predictive Value (95% CI)	Negative Predictive Value (95% CI)
Ohio Lead Risk Score ≥8	95% (92–98)	56% (49–62)	67% (61–72)	93% (87–96)
Ohio Lead Risk Score ≥10	94% (90–97)	62% (55–68)	70% (64–75)	92% (86–95)
Ohio Lead Risk Score ≥11	91% (86–94)	66% (59–72)	71% (65–76)	88% (83–93)
CDC*	95% (91–98)	41% (35–48)	60% (55–65)	91% (83–95)
ODH†	85% (79–89)	65% (59–71)	69% (64–75)	82% (76–87)

CI indicates confidence interval.
* CDC single-factor screening strategy (>27% of housing in area built before 1950).
† ODH 2-component screening strategy (CDC strategy and areas with >15% of children <5 years of age living below the poverty level).

throughout the state, these analyses suggest that certain characteristics, such as age of housing, represent global indicators of lead exposure. Other factors reflecting poverty, including mean per capita income, a regional poverty index in Massachusetts,[8] percentage of households receiving public assistance,[9] and a lower percentage of high school graduates,[10] have also been identified in earlier models as key factors. Although associations with lead exposure and race or immigrant status have been identified in previous and current models, it is likely that this relationship is confounded by economic disadvantage and does not reflect a causal association.

At a time when resources for public health are carefully allocated, it is important to validate screening programs. Although overlap with the current model exists, the studies reported to date provide estimates of these parameters using differing methods or have limitations that make difficult an assessment of their utility in other settings. Sargent et al[9] developed a model that explained much of the variation ($R^2 = .83$) within their dataset on screening for childhood lead poisoning in Rhode Island. The application of such a model outside of this small state may be difficult in the absence of other information that suggests its validity. Another model, described by Lanphear and colleagues[10] from lead screening data in Monroe County, New York, indicated somewhat lower utility, compared with the model presented here (area under the ROC curves value = .76 [standard error: .0034]). In contrast, the same parameter in the derivation and validation dataset of the Ohio Lead Risk Score (.878 and .859, respectively) suggests both better predictive power and validity. The methods and results outlined here suggest the value of this approach and begin to meet the challenge issued by the CDC to create innovative approaches to lead screening at the regional level. Indeed, discussions are currently ongoing at the ODH to incorporate the scoring system reported here into new screening initiatives planned throughout the state. Scoring systems such as these can, for example, be developed for widespread clinical use in physicians' office by combining them with census tract mapping software in Internet applications posted by state or regional public health organizations.[10] Such an approach generates an estimate of lead exposure risk for individual patients with the entry of the patient's street address and permits immediate, targeted, cost-efficient screening.

In applying the Ohio Lead Risk Score to target screening programs, we suggest a threshold of 10 points be used (Table 3). Compared with state or federally recommended approaches, this strategy has better predictive value and sensitivity, both features essential in implementing programs with limited resources. In areas where lead toxicity prevalence or sources of lead exposure differ from those found in Ohio, however, we suggest that public health officials select a lead risk score threshold with testing parameters that best suits their communities' needs. Although a high degree of model sensitivity is desirable in identifying census tracts where efforts at remediation should be focused, high specificity is an important consideration in communities where resources for screening or remediation are limited.

In the future, as testing data accumulate and are combined with census tract data or other community characteristics, new components of a lead risk scoring system may be identified to create more robust models and supercede the model described here. This approach seems sensible in developing ways to better target lead screening at both a regional and federal level. One note of caution in using this system should be considered, however. It must be clear from the outset that this score identifies geographic units where risk for lead toxicity is high. It cannot be used to predict the risk for individual children.

CONCLUSION

The Ohio Lead Risk Score described here suggests an efficient model for predicting areas where children are at high risk for having elevated BPb levels and where previous screening data identifying lead risk hot spots are not available. By identifying areas where lead toxicity is endemic before a screening program is implemented, the model may enhance the cost-efficiency of case detection and the overall success of targeted intervention efforts. Although valid for application in Ohio in a broad variety of settings, this model may be less useful in other states where the prevalence or sources of lead exposure differ. Nonetheless, this approach may have value in addressing other environmentally related health problems and in contributing to a more efficient and effective national lead screening strategy.

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