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Findings of a Statewide Environmental Lead Inspection Program Targeting Homes of Children With Blood Lead Levels as Low as 5 μg/dL

Rachel Cluett, MPH; Abby Fleisch, MD, MPH; Kathy Decker, MPH; Eric Frohmberg, MA;
Andrew E. Smith, ScD, SM

ABSTRACT

Context: There are limited data on the nature of environmental lead hazards identified during residential inspections for child blood lead levels (BLLs) of less than 10 μg/dL. We compare inspection findings for child BLLs of 5 to 9 μg/dL versus 10 μg/dL or more.

Design: We reviewed inspection reports in Maine from September 2016 to March 2018. We used continuity-adjusted or Fisher's exact test for categorical variables and Wilcoxon rank-sum tests for continuous variables to compare differences in child, family, household, and lead hazard characteristics between BLL categories (5-9 μg/dL vs ≥10 μg/dL). We used Spearman correlation coefficients to assess relationships between home surface lead dust measurements and BLLs.

Results: Of 351 residential inspections, 272 (77%) were for children with BLLs of 5 to 9 μg/dL. Children with BLLs of 5 to 9 μg/dL as compared with children with BLLs of 10 μg/dL or more were less likely to chew window sills and door frames (8% vs 21%; $P = .01$), but otherwise were similar with respect to other established risk factors for lead poisoning. Children with BLLs of 5 to 9 μg/dL tended to have fewer paint hazards inside their homes (64% vs 78%; $P = .03$), and they were more likely to have dust-only hazards (8% vs 3%) or no identified lead paint hazards (23% vs 15%), though these differences were not statistically significant. For children with BLLs of 5 to 9 μg/dL, BLL was weakly correlated with average window sill dust level (Spearman $r = 0.16$; $P = .01$) and average floor dust level ($r = 0.13$; $P = .03$), but these correlations were not observed for children with BLLs of 10 μg/dL and higher.

Conclusions: We have found that inspections of homes of children with BLLs of 5 to 9 μg/dL are nearly as likely to identify lead hazards that require abatement as inspections of homes of children with BLLs of 10 μg/dL.

KEY WORDS: blood lead levels, childhood lead poisoning, environmental inspections, lead dust levels, lead paint hazards

Author Affiliations: *Harvard T.H. Chan School of Public Health, Boston, Massachusetts (Ms Cluett); Maine Medical Center for Outcomes Research and Evaluation, Maine Medical Center Research Institute, Portland, Maine (Dr Fleisch); Muskie School of Public Service, University of Southern Maine, Portland, Maine (Ms Decker); Maine Childhood Lead Poisoning Prevention Unit (Mr Frohmberg) and Maine Environmental and Occupational Health Program (Dr Smith), Maine Center for Disease Control, Augusta, Maine.*

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Correspondence: *Andrew E. Smith, ScD, SM, Maine Environmental and Occupational Health Program, Maine Center for Disease Control, 286 Water St, SHS#11, Augusta, ME 04330 (andy.e.smith@maine.gov).*

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There is a strong body of evidence that blood lead levels (BLLs) below 10 μg/dL negatively affect cognitive ability and behavior in children.[1-4] Lead-contaminated home dust, to which children are particularly vulnerable due to crawling behavior and normal hand-to-mouth activity, is a major source of lead exposure.[5,6] In 2012, the Centers for Disease Control and Prevention's (CDC's) Advisory Committee on Childhood Lead Poisoning Prevention (ACCLPP) recommended CDC replace its recommended blood lead "level of concern" of 10 μg/dL with a blood lead "reference level" of 5 μg/dL.[1] The ACCLPP further recommended that environmental inspections to identify and remediate sources of lead exposure should be conducted in the homes of children found to have a confirmed BLL at or above the new reference level. In principle, CDC concurred with all of the recommendations approved by the

ACCLPP and adopted a blood lead reference level of 5 μg/dL.[1]

Few states or localities have adopted the ACCLPP's recommendation that environmental inspections be performed at BLLs from 5 to 9 μg/dL. There are several reasons for this, including (1) limited resources to support the substantial increase in inspections and resulting lead abatement costs, (2) uncertainty about whether environmental inspections at lower BLLs will routinely identify hazards that can be mitigated, and (3) uncertainty about whether interventions can reliably and consistently lower BLLs that are already less than 10 μg/dL.

Maine is one of the first states to require environmental inspections at BLLs from 5 to 9 μg/dL (Maine DHHS Rules, 10-144, Chapter 292).[7] In this study, we report environmental inspection results from nearly 2 years of performing inspections in homes of children younger than 6 years with venous BLLs of 5 to 9 μg/dL. We compare these inspection results in homes of children with a BLL at or above Maine's previous intervention BLL of 10 μg/dL. The primary objectives of this study were to determine (1) the frequency with which lead hazards that warrant abatement orders are identified in homes of children in the lower blood lead category (5-9 μg/dL) than in the higher category ($\geq$10 μg/dL), (2) whether the nature of the hazards differs between the 2 BLL categories, and (3) whether other housing and child characteristics differ between the 2 BLL categories. In secondary analyses, we additionally investigated the impact of using the higher Environmental Protection Agency (EPA) lead dust standards versus the lower (and recently revised) US Department of Housing and Urban Development (HUD) lead dust action levels on the frequency with which hazards are identified in the homes of lead-poisoned children.[8,9] We also performed an exploratory analysis to investigate whether existing lead abatement methods can lower BLLs that are already less than 10 μg/dL.

Methods

Study population and design

All children reported to Maine's Childhood Lead Poisoning Prevention Program (MCLPPP) case management system between September 1, 2016, and March 31, 2018, were evaluated for inclusion in the study population. Children were excluded from the study population for the following reasons: (1) they did not have a completed environmental inspection at the primary residence or the inspection occurred prior to the venous blood lead measurement; (2) the child's home had visual evidence of fresh painting prior to the inspection; (3) the family had already received guidance on remediating home lead hazards (Maine's policy prior to 2016 for children with BLLs 5-9 μg/dL); and (4) the child had another sibling included in the study. This research was approved by the institutional review boards of Harvard T.H. Chan School of Public Health and Maine Medical Center Research Institute.

BLL measurement

By state law, all children in Maine with Medicaid insurance are required to have a blood lead test (either capillary or venous) at 1 and 2 years of age and those without Medicaid insurance are required to have blood lead testing if they are at risk. State law and rules define lead poisoning as a confirmed (venous) BLL of 5 μg/dL or more and stipulate confirmation with a venous draw with state of Maine Health and Environmental Testing Laboratory (HETL) analysis. Blood specimens were analyzed for lead using graphite furnace atomic absorption (AAnalyst 600; PerkinElmer Inc, Shelton, Connecticut). The Maine HETL is CLIA certified and participates in the Wisconsin State Laboratory of Hygiene blood lead proficiency testing program.

Environmental lead inspections

For each child reported to the Maine Childhood Lead Poisoning Prevention Unit (MCLPPU) with a venous BLL of 5 μg/dL or more, the MCLPPP staff called the legal guardian to confirm the child's age, current address, insurance type (public, private, none), age of home, and whether the home was single-family owner-occupied or rented. Next, licensed risk assessors conducted environmental lead inspections in accordance with agency rules to determine potential sources of lead exposure in the primary home of each child (Maine DEP 06-096 Chapter 424, Section 7).[10]

To identify lead-based paint, risk assessors used x-ray fluorescence (XRF) and visual inspection. They tested paint on the outside of the house and in each room inside the home, including painted floors, walls, window sills, and window troughs. The risk assessors classified paint as a lead hazard if it (1) had a lead level at or above 1.0 mg/cm^2 by XRF and (2) was visually in a deteriorated condition (eg, painted surfaces peeling, chipping, chalking or cracking, or otherwise damaged or separated from the substrate). We considered the home to have a lead paint hazard if the risk assessors determined at least one painted surface to be a hazard.

To identify lead dust hazards, risk assessors sampled the highest-risk surfaces in the highest-risk rooms of the home. Risk assessors selected rooms for dust sampling based on the guardian's description of child activity patterns. Rooms commonly included the child's bedroom, primary play area, kitchen, and principal entryway. In each room, risk assessors sampled dust on sills and troughs of windows that were accessible to the child and/or reported by the guardian to be opened and closed frequently and/or reported to be areas where the child frequently played. In each room, risk assessors sampled dust on areas of the floor near friction (eg, windows, doors) or impact surfaces (eg, stairs, floors) and/or high foot traffic. In multifamily buildings, common area floor and/or window sill dust samples were collected if risk assessors determined that the location was frequented by the child. Risk assessors used a wipe technique for dust sampling (Maine DEP 06-096 Chapter 424; Appendix A).[10] Maine HETL analyzed all dust samples according to USEPA Method 6010B using an optical spectrometer (Optima 4300DV; PerkinElmer Inc). A surface was classified as a dust hazard if lead dust exceeded EPA regulatory standards (floors: 40 $\mu g/ft^2$; window sills: 250 $\mu g/ft^2$; window troughs: 400 $\mu g/ft^2$). We considered the home to have a dust hazard if the risk assessors determined at least one surface to be a dust hazard. We additionally noted whether dust hazards exceeded the HUD dust action levels (floors: 10 $\mu g/ft^2$; window sills: 100 $\mu g/ft^2$; window troughs: 100 $\mu g/ft^2$). We calculated the maximum and average lead dust levels for each surface type in each home.

During the environmental inspection, risk assessors also evaluated lead levels in water and soil. The methods for sampling and analysis of water and soil sampling are detailed in the Supplemental Digital Content material (available at http://links.lww.com/JPHMP/A521). Risk assessors also administered a questionnaire to the legal guardian to collect data on child behaviors, housing characteristics, occupational and hobby hazards, and toy and antique furniture hazards and only for immigrant families use of imported cosmetics, canned food, herbal treatment, or home remedies.

Statistical methods

We used continuity-adjusted or Fisher's exact χ^2 test for categorical variables and Wilcoxon rank-sum tests for continuous variables to compare differences in child, family, household, and lead hazard characteristics between BLL categories (5-9 μg/dL vs ≥10 μg/dL). We used Spearman correlation coefficients to assess relationships between home lead level measurements and BLLs. We used the EPA dust lead standards for all primary analyses.

In secondary analyses, we used Wilcoxon rank-sum tests to compare the higher EPA dust lead standards versus the lower HUD dust lead action levels among all children and between BLL categories. Finally, we performed an exploratory analysis to investigate whether existing lead abatement methods can lower BLLs in children with preabatement BLLs of 5 to 9 μg/dL for a subset of children (n = 32) who had a follow-up blood test 1 to 6 months postabatement and who we could confirm lived in the same dwelling pre- and postabatement.

All analyses were conducted in SAS version 9.4 (SAS Institute, Cary, North Carolina).

Results

Population characteristics

There were 482 children with an elevated venous BLL (≥5 μg/dL) reported to the MCLPPP case management system between September 1, 2016, and March 31, 2018. We excluded 38 children who did not have an environmental inspection at their primary residence, 15 children for whom the environmental inspection occurred before the venous blood lead measurement, 1 child whose home had visible fresh paint applied just prior to the inspection, 49 children who had already received guidance on remediating home lead hazards (Maine's policy prior to 2016 for children with BLLs 5-9 μg/dL), and 28 children with a sibling already included in the study. Thus, our final sample included 351 children. As compared with those excluded (n = 131), children included in the study were younger but did not differ significantly with respect to BLL, age of home, or receipt of Medicaid insurance (see Supplemental Digital Content Table 1, available at http://links.lww.com/JPHMP/A521).

Median (IQR; range) child age was 1.4 (1.1; 0.5-5.6) years. Seventy-three percent of children had Medicaid insurance. Thirty-one percent of homes were owned, 87% were built pre-1950, and 38% had a renovation within the past 6 months. Child BLLs ranged from 5 to 45 μg/dL, with 77% of children having BLLs from 5 to 9 μg/dL (Table 1).

Children with BLLs of 5 to 9 μg/dL were less likely to chew window sills and door frames than children with BLLs of 10 μg/dL or more (8% vs 21%; P = .002). These children also waited longer for an environmental inspection (4 vs 3 weeks; P = .001), reflecting the nature of how inspections are prioritized by the state. Children in the lower BLL category were less likely to exhibit mouthing behavior and spend 10 hours or more per week outside the home, although these differences did not reach statistical significance (Table 1).

TABLE 1
Child and Housing Characteristics Overall[a] and by BLL Category

	Overall (N = 351)	BLL 5-9 μg/dL (n = 272)	BLL $\geq$10 μg/dL (n = 79)
Child characteristics			
BLL,[c] median (IQR), μg/dL	6.0 (4.0)	6.0 (2.0)	13.0 (8.0)
Age, median (IQR), y	1.4 (1.1)	1.4 (1.1)	1.5 (1.0)
Chews window sills, door frames,[d] %	11	8	21
Puts hands and/or objects in mouth, %	48	46	57
Spends $\geq$10 h/wk outside home, %	25	24	28
Medicaid insurance, %	73	75	67
Parental occupation with possible lead exposure %	17	17	16
Time living in home at blood draw, median (IQR), mo	18.0 (38.8)	20.4 (39.5)	13.7 (28.7)
Housing characteristics			
Home owned (vs rented), %	31	32	30
Age of home, %[b]			
Pre-1950	87	87	90
1950-1978	7	8	3
Post-1978	6	6	7
Renovation within past 6 mo, %	38	38	38

Abbreviation: BLL, blood lead level.

[a] *Missing data for participants overall (N = 351): 3 participants missing Medicaid status, 3 housing status, 50 house year, 21 parental occupation, 35 child time out of home, 42 child chews surfaces, 39 child puts hands/objects in mouth, 57 time living in home.*

[b] *Because of rounding, the percentages may not sum to 100.*

[c] *Significant at a P value of .001.*

[d] *Significant at a P value of .01.*

Inspection characteristics

Assessors obtained a floor dust sample in 100% of homes: mean (SD) = 6.6 (2.5) samples per home; window sill dust sample in 97% of homes: mean (SD) = 3.6 (1.6) samples per home; and window trough dust sample in 55% of homes: mean (SD) = 1.6 (1.4) samples per home. Assessors tested the same number of surfaces for lead dust regardless of BLL category: mean (SD) floors 6.7 (2.6) vs 6.5 (2.3); window sills 3.7 (1.6) vs 3.5 (1.5); window troughs 1.6 (1.4) vs 1.6 (1.5), in the lower vs higher BLL category. The number of XRF lead paint measurements was not readily available from the MCLPPU case management system. Assessors evaluated many surfaces for lead paint in each home depending on the surface types they observed and the size of the home.

Lead hazard characteristics

Assessors identified lead paint or EPA standard dust hazards that required an abatement in 79% of all homes. They identified hazards almost as frequently in homes of children with BLLs of 5 to 9 μg/dL as compared with those with BLLs of 10 μg/dL or more (77% vs 85%; $P = .19$). Children with BLLs of 5 to 9 μg/dL were less likely to live in homes with interior paint hazards (64% vs 78%; $P = .03$; Table 2) and were more likely to live in homes with only dust hazards or no detectable lead hazards, although these differences were not statistically significant (global $P = .09$; Figure).

Children with BLLs of 5 to 9 μg/dL as compared with children with BLLs of 10 μg/dL lived in homes with lower average window sill dust levels (medians of 50 $\mu g/ft^2$ vs 102 $\mu g/ft^2$; $P = .18$), but there was no difference in floor dust levels (medians of 8.4 $\mu g/ft^2$ vs 7.3 $\mu g/ft^2$) (Table 2). In the full cohort, BLL was weakly correlated with average window sill dust level (Spearman $r = 0.14$; $P = .009$), but not with average floor dust level ($r = 0.06$; $P = .29$). When restricted to children with BLLs of 5 to 9 μg/dL, correlations between BLL and window sill lead dust level were stronger ($r = 0.20$; $P = .001$) and BLL was weakly correlated with average floor dust level ($r = 0.13$; $P = .03$). BLL was not correlated with either floor or window sill dust levels for children with BLLs of 10 μg/dL and above.

TABLE 2
Severity of Lead Hazards by BLL Category

	BLL 5-9 μg/dL (n = 272)	BLL ≥10 μg/dL (n = 79)	P
Higher exposure potential			
Interior (vs outside or not at all) paint hazard,[a] %	64	78	.03
Multiple surface types (floor, window sill, window trough) with dust hazard,[b] %	31	34	.86
Multiple surfaces with dust hazard,[b] %	43	46	.9
Dust lead level			
Window sill (dwelling average), median (IQR), μg/ft^2	50 (222)	102 (258)	.18
Floor (dwelling average), median (IQR), μg/ft^2	8.4 (26.3)	7.3 (17.5)	.67

Abbreviationss: BLL, blood lead level; XRF, x-ray fluorescence.

[a] Paint hazard is defined as a paint surface that (1) tests positive for lead with an XRF gun and (2) is in poor condition (eg, peeling, chipping) as determined by the lead risk assessor.

[b] Dust hazard is defined as a surface sampled by the lead risk assessor that meets or exceeds the Environmental Protection Agency lead threshold: floors ≥40 μg/ft^2; window sills ≥250 μg/ft^2; window troughs ≥400 μg/ft^2.

Few homes had water lead hazards, and differences in soil lead hazards between BLL categories were consistent with differences for paint and dust hazards between categories. We present detailed results of soil and water testing in the Supplemental Digital Content material (available at http://links.lww.com/JPHMP/A521).

Secondary analyses

In our data set comprising inspections associated with a sizeable number of children with BLLs of 5 to 9 μg/dL, we found that use of the lower HUD dust lead action levels resulted in twice as many homes with a "dust-only" lead hazard (14% using HUD action levels vs 7% using EPA standards) and considerably fewer homes without any lead hazards (15% using HUD action levels vs 21% using EPA standards). We identified both floor and window sill dust hazards more frequently when we used the lower HUD action levels as compared with the EPA standards (66% vs 38% floor dust hazards and 53% vs 38% sill dust hazards) (Table 3). When we compared window sill dust hazards among children with BLLs of 5 to 9 μg/dL versus children with BLLs of 10 μg/dL or more, we found a greater discrepancy between BLL categories when we used HUD action levels (49% vs 69%; $P = .01$) versus EPA standards (36% vs 46%; $P = .15$). In contrast, differences between BLL categories were minor and nonsignificant for floor dust hazards. When we identified dust hazards with the HUD action levels as compared with the EPA standards, we identified more homes that required abatement due to a paint or dust hazard (86% vs 79%; $P = .03$).

In a final secondary analysis, we explored the extent to which lead abatement reduced BLLs in children

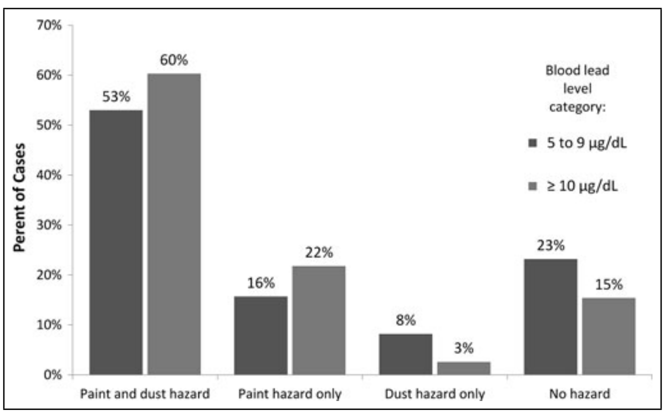

FIGURE Lead Paint and Dust Hazards by BLL Category. Global *P* Value of .09 Indicates Difference Across Categories by BLL; Fisher's Exact Test Reported[a]

[a]Dust hazard is defined as a surface sampled by the lead risk assessor that meets or exceeds the Environmental Protection Agency lead threshold: floors ≥40 μg/ft^2; window sills ≥250 μg/ft^2; window troughs ≥400 μg/ft^2.

TABLE 3
Comparison of US EPA Standards and HUD Action Levels for Lead Dust Among All Inspected Homes

	Dust Thresholds		
	EPA	HUD	P^a
Any dust hazard,[b] %	62	80	<.0001
Floor dust hazard,[b] %	38	66	<.0001
Sill dust hazard,[b] %	38	53	.0001

Abbreviations: EPA, Environmental Protection Agency; HUD, US Department of Housing and Urban Development.

[a]P value indicates significance of the difference between using EPA and HUD dust standards to determine whether lead level is considered a hazard. Continuity-adjusted χ^2 statistic is reported.

[b]Dust hazard is defined as a surface sampled by the lead risk assessor that meets or exceeds the EPA lead standard: floors $\geq$40 μg/ft^2; window sills $\geq$250 μg/ft^2; window troughs $\geq$400 μg/ft^2 or the HUD lead action levels: floors $\geq$10 μg/ft^2; window sills $\geq$100 μg/ft^2; window troughs $\geq$100 μg/ft^2.

with BLLs of 5 to 9 μg/dL. On average, a postabatement BLL was obtained 2.8 months after the abatement. Of the 32 children who met criteria for inclusion in this analysis, 1 (3%) had a BLL that increased by 3 μg/dL postabatement, 4 had the same BLL postabatement (12.5%), 10 (31%) had a decrease in BLLs of 15% to 40%, and 17 (53%) had a decrease of 40% or more. Additional information and results are presented in the Supplemental Digital Content material (available at http://links.lww.com/JPHMP/A521).

Discussion

We analyzed data from one of the first states to implement environmental lead inspections in homes of children with BLLs of 5 μg/dL or more. While there were fewer lead hazards in homes of children with BLLs of 5 to 9 μg/dL, these homes required abatement 77% of the time, almost as frequently as homes of children with higher BLLs. In a subset of our cohort, we show that following abatement, BLLs substantially decreased in the vast majority of children with BLLs of 5 to 9 μg/dL. Among children with lower BLLs, our data suggest that environmental lead inspections identify lead hazards that may benefit from remediation.

We found that children with BLLs of 5 to 9 μg/dL versus 10 μg/dL or more were less likely to have self-reported chewing behavior but otherwise did not significantly differ on established risk factors for elevated BLLs (eg, hand-to-mouth activity, insurance status, age of housing, recent home renovation). This is in contrast to a prior analysis of NHANES (National Health and Nutrition Examination Survey) data that reported increased odds of higher BLLs for children with public insurance or who lived in pre-1946 housing.[11] The different results may be because a majority of children in our study lived in older homes and had public insurance, masking potential variability between BLL categories.

The dominant sources of lead exposure for children with BLLs less than 10 μg/dL have not been well characterized in prior research, and some have suggested that no single exposure source is dominant.[12] However, our study indicates that, while in a small proportion of cases the dominant exposure sources may have been outside of the home, lead paint and/or dust are found inside a vast majority of homes of Maine children with BLLs of 5 to 9 μg/dL.

Lead hazards tended to be fewer and less severe in homes of children with BLLs of 5 to 9 μg/dL versus higher BLLs (fewer interior paint hazards, more dust-only hazards), suggesting that while abatement was often necessary, costs should, on average, be lower for children with BLLs of 5 to 9 μg/dL versus 10 μg/dL or more. EPA economic analyses indicate that, on average, dust hazards are less costly to remediate than paint hazards and exterior paint hazards are less costly to remediate than interior paint hazards.[13]

We observed an association between BLLs and window sill lead dust levels, consistent with the existing literature.[6,14-16] However, divergent from existing literature, we observed only an association between BLLs and floor lead dust levels among children with BLLs of 5 to 9 μg/dL.[14,17,18] Guardians of children in this study were instructed to implement interim controls (eg, wet mop cleaning) to reduce hazards while awaiting inspection, whereas in prior studies, measures were explicitly taken by researchers to prevent disturbing dust before sampling occurred. The absence of a strong relationship between BLLs and floor dust levels in our study is consistent with data suggesting that families may adhere to interim control recommendations for cleaning floors more readily than for cleaning window sills, clean floors more often than they do sills, or that lead dust on window sills returns more quickly than on floors.[18]

Results from our study add to existing literature indicating that the current EPA dust hazard standards are not stringent enough. In our data set comprising inspections for a majority of children with BLLs of 5 to 9 μg/dL, we found that the lower HUD dust lead action levels identified twice as many homes with a "dust-only" lead hazard and fewer homes with no lead hazards. Our results are in line with prior studies that have shown children with elevated BLLs live in homes with detectable lead dust at levels lower than current EPA standards and HUD action levels.[6,14,15,18] Specifically, in a nationally representative cross-sectional study of children between 1 and 5 years old, Dixon et al[14] found that the probability of a child having a blood level of 5 μg/dL or more at the EPA floor standard (40 $\mu g/ft^2$) is 52% and the probability of an elevated BLL of 5 μg/dL or more at the HUD floor action level (10 $\mu g/ft^2$) is 24%.

An outstanding question related to performing inspections at lower BLLs is whether existing lead abatement methods and clearance standards can lower BLLs that are already less than 10 μg/dL.[1] Our exploratory secondary analysis in a small subset of children suggests that for children with BLLs of 5 to 9 μg/dL, abatement activity was much more likely to be associated with a lower BLL than either a higher BLL or no change in BLL. Our results are consistent with other studies that have compared pre- versus postabatement BLLs in children with BLLs of 5 to 9 μg/dL.[19-21] In this small analysis, we cannot rule out the possibility that the changes in BLLs that we observe are attributed in part to season of blood draw or changes in child age and behavior (eg, age-related reduction in hand-to-mouth activity).

Our study is limited by a small sample size, which may have prevented some comparisons from reaching statistical significance despite potentially relevant differences (eg, percentage of homes with dust-only lead hazards). Furthermore, the generalizability of this study may be limited to states with similar housing stock (ie, Maine is one of 12 states with >25% of homes built before 1950).[22]

Leveraging case management data from the MCLPPU is a strength of our study, as it allows results to be directly extrapolated to other state or local lead poisoning prevention programs. However, the MCLPPU has an ethical obligation to provide information on interim household cleaning to families of children with elevated BLLs to reduce lead hazards while awaiting inspection. While we excluded a case where obvious changes to the home interior were made before environmental inspection (eg, painting over peeling paint), we could not control for the possibility that families and/or landlords may have taken some actions to reduce lead paint and dust hazards prior to inspections. Likewise, we cannot rule out the possibility that results were influenced by the longer inspection wait time for children with a lower BLL. A longer wait time could reduce lead hazards by providing more time for families or landlords to take action or worsen lead hazards by providing more time for friction or impact on lead paint surfaces. The existing literature indicates that dust control performed by families has limited effectiveness in reducing child lead exposure.[4,23,24]

Implications for Policy & Practice

- Maine is one of the first states to fully implement the ACCLPP's recommendation to perform environmental inspections in homes of children with BLLs of 5 to 9 μg/dL.
- We have found that inspections of these homes are nearly as likely to find identifiable lead hazards that require abatement as inspections of homes of children with BLLs of 10 μg/dL or greater.
- We have also found that lead abatement lowers BLLs further in the vast majority of children with BLLs of 5 to 9 μg/dL.
- Thus, our data suggest that performing environmental inspections in homes of children with BLLs of 5 to 9 μg/dL is a public health imperative.
- Results from our study add to existing literature indicating that the current EPA dust hazard standards are not stringent enough.

References

1. Advisory Committee on Childhood Lead Poisoning Prevention. *Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention*. Atlanta, GA: Centers for Disease Control and Prevention; 2012. https://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf. Accessed April 23, 2018.
2. National Toxicology Program. *NTP Monograph on Health Effects of Low-Level Lead*. Washington, DC: US Department of Health and Human Services; 2012.
3. Canfield RL, Henderson CR Jr, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual impairment in children with blood lead concentrations below 10 micrograms per deciliter. *N Engl J Med*. 2003;348(16):1517-1526.
4. Lanphear BP, Hornung R, Khoury J, et al. Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environ Health Perspect*. 2005;113(7):894-899.
5. Dietrich KN, Krafft KM, Bornschein RL, et al. Low-level fetal lead exposure effect on neurobehavioral development in early infancy. *Pediatrics*. 1987;80(5):721-730.
6. Lanphear BP, Matte TD, Rogers J, et al. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels. A pooled analysis of 12 epidemiologic studies. *Environ Res*. 1998;79(1):51-68.
7. Maine Department of Health and Human Services. State of Maine rules relating to the Lead Poisoning Control Act of 2016, 10-144, chapter 292 (2016). https://www.maine.gov/sos/cec/rules/10/chaps10.htm. Accessed August 1, 2017.
8. US Environmental Protection Agency. Part III, 40 CFR Part 745 Lead; Identification of dangerous levels of lead; Final rule. https://www.gpo.gov/fdsys/pkg/FR-2001-01-05/pdf/01-84.pdf. Pubished January 5, 2001. Accessed August 1, 2017.
9. US Department of Housing and Urban Development. Revised dust-lead action levels for risk assessment and clearance; clearance of porch floors. Policy Guidance No. 2017-01. https://www.hud.gov/sites/documents/LEADDUSTCLEARANCE.PDF. Published January 31, 2017. Accessed August 1, 2017.
10. Maine Department of Environmental Protection. Maine Solid Waste Management Rules of 2016, 06-096, chapter 424 (2016). http://www.maine.gov/dep/waste/rules/index.html. Accessed August 1, 2017.
11. Bernard SM, McGeehin MA. Prevalence of blood lead levels ≥5 μg/dL among US children 1 to 5 years of age and socioeconomic and demographic factors associated with blood of lead levels

5 to 10 μg/dL, third national health and nutrition examination survey, 1988-1994. *Pediatrics*. 2003;112(6):1308. https://search.proquest.com/docview/228381152. Accessed April 23, 2018.
12. Levin R, Brown MJ, Kashtock ME, et al. Lead exposures in U.S. children, 2008: implications for prevention. *Environ Health Perspect*. 2008;116(10):1285-1293. http://www.jstor.org/stable/25071177. Accessed April 23, 2018.
13. US Environmental Protection Agency. *Economic Analysis of Toxic Substances Control Act Section 403: Lead-Based Paint Hazard Standards*. Washington, DC: US Environmental Protection Agency; 2000.
14. Dixon SL, Gaitens JM, Jacobs DE, et al. Exposure of U.S. children to residential dust lead, 1999-2004, part II: the contribution of lead-contaminated dust to children's blood lead levels. *Environ Health Perspect*. 2009;117(3):468-474.
15. Lanphear BP, Weitzman M, Winter NL, et al. Lead-contaminated house dust and urban children's blood lead levels. *Am J Public Health*. 1996;86(10):1416-1421.
16. Lanphear BP, Roghmann KJ. Pathways of lead exposure in urban children. *Environ Res*. 1997;74(1):67-73.
17. Gasana J, Hlaing W, Siegel KA, Chamorro A, Niyonsenga T. Blood lead levels in children and environmental lead contamination in Miami Inner City, Florida. *Int J Environ Res Public Health*. 2006;3(3):228-234. http://www.ncbi.nlm.nih.gov/pubmed/16968968. Accessed April 23, 2018.
18. Wilson J, Dixon S, Galke W, McLaine P. An investigation of dust lead sampling locations and children's blood lead levels. *J Expo Sci Environ Epidemiol*. 2007;17(1):2-12.
19. Galke W, Clark S, Wilson J, et al. Evaluation of the HUD lead hazard control grant program: early overall findings. *Environ Res*. 2001;86(2):149-156.
20. Clark S, Grote J, Wilson J, et al. Occurrence and determinants of increases in blood lead levels in children shortly after lead hazard control activities. *Environ Res*. 2004;96(2):196-205. https://www.sciencedirect.com/science/article/pii/S0013935103002172. Accessed April 23, 2018.
21. Clark S, Galke W, Succop P, et al. Effects of HUD-supported lead hazard control interventions in housing on children's blood lead. *Environ Res*. 2011;111(2):301-311.
22. US Census Bureau. American community survey: tenure by year structure built. https://factfinder.census.gov. Updated 2016. Accessed April 23, 2018.
23. Schultz B, Pawel D, Murphy A. A retrospective examination of in-home educational visits to reduce childhood lead levels. *Environ Res*. 1999;80(4):364-368. https://www.sciencedirect.com/science/article/pii/S0013935198939226. Accessed April 23, 2018.
24. Haynes E, Lanphear BP, Tohn E, Farr N, Rhoads GG. The effect of interior lead hazard controls on children's blood lead concentrations: a systematic evaluation. *Environ Health Perspect*. 2001;110(1):103-107.