Pediatric Blood Lead Levels Within New York City Public Versus Private Housing, 2003–2017

Jacqueline M. Chiofalo, MPA, Maxine Golub, MPH, Casey Crump, MD, PhD, and Neil Calman, MD

Objectives. To compare blood lead levels (BLLs) among children residing in public and private housing in New York City and examine the implications for lead identification and remediation policies.

Methods. We examined electronic medical records for BLLs among 4693 children receiving care at a multisite Federally Qualified Health Center during 2003 to 2017. We plotted home addresses against city housing data to assess BLL differences between children living in public housing and private housing.

Results. Only 0.25% of children residing in public housing had BLLs exceeding the upper reference limit of 5 micrograms per deciliter, as compared with 2.76% of children residing in private housing. After adjustment for age, gender, and race/ethnicity, public housing was associated with 92% lower odds of having a BLL of 5 micrograms per deciliter or above (odds ratio [OR] = 0.08; 95% confidence interval [CI] = 0.02, 0.33; $P = .001$). Decreases in BLLs were observed in both public and private housing over time.

Conclusions. Children living in public housing in New York City were significantly less likely to have elevated BLLs than were children living in private housing. Decreases in BLLs over time were likely a result of lead reduction legislation. (*Am J Public Health.* 2019; 109:906–911. doi:10.2105/AJPH.2019.305021)

See also Jacobs, p. 830.

Lead was introduced into many households through plumbing, gasoline, and paint during the early 1900s, leading to illnesses and deaths among exposed children. Since then, the negative health effects of lead have been widely studied. Elevated blood lead levels (BLLs) of 40 to 60 micrograms per deciliter (μg/dL) and repeated exposures over time can produce somatic symptoms such as vomiting, lethargy, convulsions, seizures, and coma.[1]

However, lead affects the neurological development of children even below levels at which somatic symptoms are apparent.[2–5] Among children 1 to 7 years of age, blood lead concentration is inversely related to IQ even at levels below 10 μg/dL.[3] The effects of lead on neurological and behavioral development have detrimental sequelae later in life as well. Elevated BLLs are positively associated with poorer academic performance in high school, lower vocabulary and grammatical reasoning scores, and a higher risk of dropping out of high school.[5,6] In addition, it has been shown that children with BLLs above 5 μg/dL are more likely to participate in delinquent activity.[5,7,8]

Despite increasing awareness of lead hazards, the global disease burden attributable to lead increased by an estimated 160% between 1990 and 2010.[9] Lead exposure is a leading cause of overall disease burden in virtually all regions of the world and now accounts for more than 600 000 deaths annually worldwide.[9] Lead can be introduced to humans in a variety of ways, most commonly from lead-based deteriorated paint, soil, and plumbing systems. Geographic location and living conditions are therefore important determinants of lead poisoning risk. In addition, the half-life of lead within the blood system is 1 to 2 months, making it easier to detect recent lead exposures.

A number of federal, state, and local public policies have aimed to identify, remediate, and eliminate lead exposures. Subsequent to the creation of the Environmental Protection Agency in 1970, the Lead-Based Paint Poisoning Prevention Act established lead-based paint as a public health concern in 1971, and the Consumer Product Safety Commission banned its use in all residential housing in 1978.[10] The Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X) took a proactive and preventive approach against lead poisoning in public housing by mandating completion of risk assessments by 2002 for all public housing units built before 1978.[11] Title X also requires disclosure of potential lead hazards to purchasers or lessees of dwellings built before 1978.[11] The 1991 Lead and Copper Rule made testing of drinking water mandatory in homes deemed "high risk" on the basis of plumbing components, and Clean Air Act amendments banned lead in gasoline, phasing it out entirely by 1996.[12,13]

The regulations just described helped reduce and control lead in its most common sources: paint, gasoline, and water. As a result of such initiatives, average BLLs declined 78% among US residents between 1976 and 1991.[14] The Centers for Disease Control and Prevention (CDC) also initiated surveillance programs designed to eliminate childhood lead poisoning in accordance with the Lead Contamination Control Act of 1988.[15] In 2012, the CDC adopted a BLL upper reference value of 5 μg/dL among children as a level of concern requiring environmental and educational intervention.[16]

ABOUT THE AUTHORS

The authors are with the Institute for Family Health, New York, NY. Casey Crump and Neil Calman are also with the Department of Family Medicine and Community Health, Icahn School of Medicine at Mount Sinai, New York.

Correspondence should be sent to Jacqueline M. Chiofalo, MPA, 2006 Madison Ave, New York, NY 10035 (e-mail: jchiofalo@institute.org). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

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The New York City (NYC) population includes an estimated 1.75 million children.[17] Although federal acts and regulations have eliminated major sources of lead exposures, state and local governments are responsible for addressing residual sources such as lead-based paint. The New York Public Health Law requires physicians to screen children younger than 6 years for elevated BLLs, report the results to a statewide registry, and notify state and city health departments of levels above 10 μg/dL for further follow-up, including treatment and lead remediation.[18] NYC banned lead-based paint in 1960, well before the federal government.[19]

Local legislation in NYC, most notably Local Law 1 of 2004, has established protocols for identification of lead exposures and subsequent environmental remediation in all types of housing.[20] Local Law 1 places the responsibility for lead abatement with building owners by requiring annual inspections for buildings built before 1960. The law also requires the Department of Health and Mental Hygiene (DOHMH) to report elevated BLLs among children residing in any type of housing to the Department of Housing Preservation and Development (HPD); the HPD will then inspect the housing and issue and correct a violation if a source of lead is found.[20]

In 2016, the HPD inspected nearly 26 000 privately owned buildings, issued approximately 12 000 lead violations, and corrected 826 violations in accordance with Local Law 1.[21] This law addresses the gap in regulations for private housing built before 1960, when NYC banned lead-based paint, as opposed to federal public housing regulated by Title X.[22] NYC health data show that, since 2005, BLLs have declined among children younger than 6 years, although approximately 20 of every 1000 children still have levels of 5 μg/dL or higher.[23] A 2017 investigation revealed wide variations in elevated BLLs among NYC census tracts, however, with one neighborhood having rates similar to Flint, Michigan.[24]

The New York City Housing Authority (NYCHA) has 326 federal public housing developments within the 5 boroughs of NYC that house 174 282 families, making it the largest public housing authority in the United States.[25] At least 75 NYCHA developments were constructed before 1960, and an estimated 27% of the NYCHA's 396 581 authorized residents are younger than 18 years.[25] In addition to Title X regulations, the HPD responds to lead hazards in NYCHA buildings and corrects violations per Local Law 1.[20,26]

A few prior studies have assessed housing type in relation to child lead exposures; to our knowledge, however, such an investigation has never been conducted in NYC. A 1985 study of 56 children in Cincinnati, Ohio, reported that children residing in public housing had a significantly lower mean BLL than those living in private housing, suggesting that federal regulation for public housing was effective.[27] By contrast, a 1998 study of 7121 children in New Orleans, Louisiana, showed that those living in public housing were not better protected against elevated BLLs.[28] However, these findings were based on data that preceded inspections mandated by Title X. More recently, a study of 1250 children throughout the United States in 2005 to 2012 reported that children living in public housing had lower BLLs than those living in private housing.[29] National studies do not take into account the variety of local lead laws, however, and the prior city-focused studies are now dated and involved local lead laws that differ substantially from those of NYC.[22]

Leaders at a Federally Qualified Health Center (FQHC) with multiple sites in NYC were recently approached by housing advocates with concerns about high lead exposure risks in NYCHA housing. If such risks exist, this would be contrary to most prior evidence suggesting that children in public housing are less likely to have elevated BLLs.[27,29] Using clinical data from a network of community health centers in NYC, we examined BLLs in children living in NYCHA housing as compared with private housing. Given the federal and city-wide lead laws protecting public housing, we hypothesized that children living in NYCHA housing would be less likely than those living in private housing to have BLLs of 5 μg/dL or above. To our knowledge, this is the first study to use clinical data from the electronic health records of a single community-based medical provider to examine differences in pediatric BLLs in NYC public and private housing.

METHODS

We obtained BLL data for our retrospective observational study from clinic visits that occurred between 2003 and 2017 at an FQHC organization with 17 sites in 3 of the 5 boroughs of NYC. The mission of FQHCs is to serve medically underserved communities, including low-income and uninsured individuals. Given our desire to examine potential lead poisoning in NYCHA housing, which is public housing for families with incomes 80% below the area median income, the FQHC was an ideal source of information because BLLs could be matched to patient addresses and many patients reside in public housing. The study sample comprised 4693 children aged 18 years or younger who had had their BLLs tested at the FQHC's NYC centers since 2003, the year the center implemented electronic medical records. The records assessed in the study included a unique medical record number, the home address at time of the clinic visit, date of birth, gender, race, ethnicity, the date of the clinic visit, and the BLL at the visit.

We extracted addresses of NYCHA properties from public records. Patient address information was manually cleaned and sorted to ensure accuracy and then plotted onto a map of NYCHA developments in 2016 via a geographic information system.[30] Records that were matches to NYCHA developments were coded by location within specific developments.

BLL reporting formats varied among patient records, with results reported as numeric values or ranges (< 3, < 2, and < 1 μg/dL). Range values were recoded to levels 0.5 μg/dL below the upper bound because this was considered to best approximate mean values within a given range (Bioreference Laboratories, oral communication, March 2018). For example, less than 3 was coded as 2.5 and less than 1 was coded as 0.5.

We conducted logistic regression analyses to examine housing type (NYCHA vs private) in relation to BLL as a dichotomous (≥ 5 vs < 5 μg/dL) variable. We performed both unadjusted analyses and analyses adjusted for age (continuous), gender, and race/ethnicity (non-Hispanic Black, non-Hispanic non-Black, Hispanic Black, Hispanic non-Black). In the case of patients

with more than 1 BLL measurement (n = 1053), we used the highest BLL in our analyses. Although a small number of patients changed addresses between visits (n = 168), most remained in the same housing category (public vs private) between visits. We used Stata version 15 (StataCorp LLC, College Station, TX) in all of our analyses.

RESULTS

Most of the study children resided in the Bronx (65.4%) or Manhattan (26.6%), and the most common race/ethnicity was African American (41.2%). The average age was 3.7 years, with 82.2% of children being aged 6 years or younger and most (54.7%) being aged 2 years or younger. This is reflective of local requirements to test children's BLLs at 1 and 2 years of age. Most of the children (82.7%) resided in private housing and 17.3% resided in NYCHA housing, reflecting that this was a relatively low-income population (< 10% of children in NYC overall live in NYCHA developments).[25] Among children from NYCHA housing, 59.8% lived in developments completed before 1960, the year NYC banned lead-based paint in residential interiors, and 96.5% lived in developments completed before 1978, the year the federal government banned lead-based paint. In the 2 zip codes that had the most children with BLLs of 5 μg/dL or above who lived in private housing (16 children in 1 zip code and 15 children in the other), 87.3% and 78.4% of housing units were built before 1970.[17]

Table 1 shows BLLs by patient characteristics. The overall mean BLL was 2.07 μg/dL, and the median was 2.00 μg/dL. Among all 4693 children, 2.32% had a BLL exceeding the CDC level of concern (5 μg/dL). Children who lived in private (non-NYCHA) housing had higher mean BLLs than children living in NYCHA housing (2.10 vs 1.92 μg/dL; $P < .001$), as well as a higher prevalence of BLLs of 5 μg/dL or above (2.76% vs 0.25%; $P < .001$); there was a statistically significant difference between the 2 means and the 2 percentages ($P < .001$). BLLs were lowest among children 13 to 18 years of age. Hispanic non-Black children had the lowest BLLs among the racial/ethnic groups examined, with 1.54% of these children having BLLs of 5 μg/dL or above.

TABLE 1—Demographic Characteristics of Children Receiving Services at a Federally Qualified Health Center: New York City, 2003–2017

Characteristic	No. of Patients	BLL, Mean (SD)	No. of Patients With BLLs ≥ 5 μg/dL (%)
Total	4693	2.07 (1.13)	109 (2.32)
Housing type			
Private (non-NYCHA)	3881	2.10 (1.19)	107 (2.76)
Public (NYCHA)	812	1.92 (0.76)	2 (0.25)
Gender			
Male	2344	2.08 (1.01)	57 (2.43)
Female	2349	2.06 (1.23)	52 (2.21)
Age, y			
< 6	3858	2.09 (1.12)	93 (2.41)
6–12	511	2.13 (1.26)	13 (2.54)
13–18	324	1.71 (0.91)	3 (0.93)
Race/ethnicity			
Non-Hispanic Black	1686	2.14 (1.25)	53 (3.14)
Hispanic non-Black	2137	2.00 (0.99)	33 (1.54)
Hispanic Black	249	2.03 (0.98)	4 (1.61)
Non-Hispanic non-Black	621	2.15 (1.29)	19 (3.06)

Note. BLL = blood lead level; NYCHA = New York City Housing Authority.

Table 2 shows BLL trends over time. The percentage of children with BLLs of 5 μg/dL or above decreased steadily throughout the study period. Mean BLLs also trended downward with the exception of a slight increase in 2011 to 2014, which was followed by a subsequent decrease during 2015 to 2017. Although there were few NYCHA residents in the study sample in 2003 to 2006 (n = 15) and 2007 to 2010 (n = 106), the percentage of children with BLLs of 5 μg/dL or above remained at or near zero.

As noted, we conducted logistic regression analyses to examine associations between housing type and BLLs (Table 3). In the unadjusted model, children living in NYCHA housing were 92% less likely to have BLLs of 5 μg/dL or above than children living in private housing (odds ratio [OR] = 0.08; 95% confidence interval [CI] = 0.02, 0.35; $P = .001$). As an alternative measure, we conducted an exact logistic regression analysis to account for potential skewed results, and this analysis yielded an identical odds ratio (OR = 0.08; 95% CI = 0.01, 0.32; $P < .001$). There were only negligible changes in these results after adjustment for age, gender, and race/ethnicity (OR = 0.08; 95% CI = 0.02, 0.33; $P = .001$). Hispanic non-Black children had significantly lower odds of having elevated BLLs than non-Hispanic non-Black children (adjusted OR = 0.51; 95% CI = 0.29, 0.91; $P = .02$). Age and gender were not significantly associated with risk of BLLs of 5 μg/dL or above.

To assess whether NYCHA housing was associated with lower BLLs in more recent years after overall BLLs had declined, we conducted sensitivity analyses in which we restricted data to the years 2011 to 2017. Logistic regressions adjusting for age, gender, and race/ethnicity showed that children living in NYCHA housing still had significantly lower odds of having BLLs of 5 μg/dL or above (OR = 0.16; 95% CI = 0.03, 0.67; $P = .01$). We also repeated our main analysis after restricting the sample to children younger than 6 years, given the more pronounced consequences of lead exposure at young ages. Again, the results were minimally affected and the conclusions were unchanged. After adjustment for age, gender, and race/ethnicity, children living in NYCHA housing had significantly lower odds of having BLLs of 5 μg/dL or above (OR = 0.10; 95% CI = 0.02, 0.41; $P = .001$).

TABLE 2—Blood Lead Level (BLL) Results Over Time, by Housing Status, Among Children Receiving Services at a Federally Qualified Health Center: New York City, 2003–2017

	All Children			NYCHA Residents			Non-NYCHA Residents		
Study Years	No.	BLL, Mean (SD)	No. With BLLs ≥ 5 μg/dL (%)	No.	BLL, Mean (SD)	No. with BLLs ≥ 5 μg/dL (%)	No.	BLL, Mean (SD)	No. With BLLs ≥ 5 μg/dL (%)
2003–2006	138	2.89 (1.38)	16 (11.5)	15	2.26 (1.00)	0 (0.00)	123	2.96 (1.40)	16 (13.01)
2007–2010	793	2.18 (1.25)	40 (5.04)	106	1.90 (0.85)	0 (0.00)	687	2.23 (1.29)	40 (5.82)
2011–2014	2068	2.44 (0.80)	34 (1.64)	390	2.36 (0.49)	1 (0.26)	1678	2.46 (0.86)	33 (1.97)
2015–2017	1694	1.50 (1.10)	19 (1.12)	301	1.34 (0.62)	1 (0.33)	1393	1.54 (1.23)	18 (1.29)

Note. NYCHA = New York City Housing Authority.

DISCUSSION

In our study, the percentage of NYC children with BLLs of 5 μg/dL or above (2.32%) was slightly higher than that previously reported by the DOHMH (2.08%).[23] Our findings suggest that children living in NYCHA housing have lower BLLs than children living in private housing.

TABLE 3—Associations Between Selected Variables and Blood Lead Levels (BLLs) ≥ 5 μg/dL Among Children Receiving Services at a Federally Qualified Health Center: New York City, 2003–2017

	BLL ≥ 5 μg/dL	
Variable	Unadjusted[a] OR (95% CI)	Adjusted OR (95% CI)
Housing type		
NYCHA	0.08 (0.02, 0.35)	0.08 (0.02, 0.33)
Non-NYCHA	1 (Ref)	1 (Ref)
Gender		
Male	1 (Ref)	1 (Ref)
Female	0.90 (0.62, 1.32)	0.98 (0.66, 1.44)
Age, y		
< 6	1 (Ref)	1 (Ref)
6–12	1.0 (0.58, 1.90)	1.09 (0.60, 1.98)
13–18	0.37 (0.11, 1.20)	0.38 (0.12, 1.24)
Race/ethnicity		
Hispanic Black	0.51 (0.17, 1.53)	0.59 (0.19, 1.77)
Hispanic non-Black	0.49 (0.28, 0.88)	0.51 (0.29, 0.91)
Non-Hispanic Black	1.02 (0.60, 1.75)	1.15 (0.67, 1.96)
Non-Hispanic non-Black	1 (Ref)	1 (Ref)

Note. CI = confidence interval; NYCHA = New York City Housing Authority; OR = odds ratio.
[a]Reported values are for each variable without control for other covariates.

Specifically, children who lived in NYCHA housing had lower mean BLLs than children who lived in private housing (1.92 μg/dL vs 2.10 μg/dL), and only 0.25% (vs 2.76%) had BLLs exceeding the CDC reference level of 5 μg/dL. After adjustment for sociodemographic factors, children living in NYCHA housing had 92% lower odds of having elevated BLLs. These findings are consistent with those of prior studies suggesting the protective effects of public housing and regulations that identify and remediate environmental lead exposures.[27,29]

The incidence of elevated BLLs within NYCHA developments remained stable and very low from 2003 to 2017 in our patient population. No NYCHA development had more than 1 child with an elevated BLL. We also found that BLLs decreased over time. The large decreases in the number of children with BLLs of 5 μg/dL or above between 2003 to 2006 and 2007 to 2010 may be related to NYC's Local Law 1 of 2004, which mandates inspections of all apartments housing children younger than 6 years, abatement of identified lead contaminants, and interagency cooperation among city departments, primarily the HPD and the DOHMH.[20]

Our results suggest that living in public housing is associated with lower lead exposures among children and that governmental oversight and intervention, such as Title X and Local Law 1, have had important public health benefits. There have been significant decreases in BLLs among children living in private housing since 2003, whereas children residing in NYCHA housing and receiving care at the FQHC maintained an elevated BLL prevalence of nearly zero from 2003 to 2017. In addition, although most NYCHA developments were built before 1960, children in public housing still had lower BLLs. This may be attributable to federal housing policies, specifically Title X, that sought to detect and remediate lead hazards in all public housing units by 2002, the year before our data collection began.[11,31] We also found that the zip codes for private housing with the most children who had BLLs of 5 μg/dL or above had a high prevalence of older housing units.[17]

Although we lacked complete data on housing age, these findings suggest that older private but not public housing poses high lead exposure risks. Our results are consistent with most published evidence and suggest the effectiveness of federal agency oversight in identifying and correcting lead violations.[27,29] Given the sustained presence of elevated BLLs in non-NYCHA housing, Local Law 1 of 2004 may need tighter enforcement in privately owned buildings and homes, especially homes with small children. Previous evidence suggests that strict enforcement of lead poisoning prevention policies is an effective strategy.[32] It is also recommended that the NYCHA continue to certify lead inspections and that sufficient funding be appropriated to ensure all work orders regarding lead are resolved in a timely manner.

Limitations and Future Research

One of the limitations of our study was the uncertain generalizability across the population of children in NYC. Notably, children were not distributed evenly across the 5 boroughs, especially in areas such as Williamsburg, where a higher incidence of lead poisoning has been reported.[24] However, the sample does provide insights into the distribution of lead exposures across housing

facilities and time trends in Manhattan and the Bronx, where a majority of the FQHC's practices are located. In addition, the accuracy and timeliness of the address information in our electronic medical record data are uncertain, and information on children's tenure at their current housing unit was not collected. However, misclassification of housing type would likely influence our findings conservatively (i.e., toward the null hypothesis). Also, we lacked more specific information on different types of private housing (e.g., owner occupied, rental unit) and on private housing age, instead relying on aggregated census data. Finally, we lacked data on the rate of lead testing at the FQHC.

Lead exposure remains a severe public health problem throughout the world.[9] Immigrant children in NYC have been reported to be at an elevated risk of lead poisoning, potentially related to prior lead exposures in their country of origin or continued use of imported, contaminated products.[24,33] Information on patients' immigration status was not collected or analyzed, and data on immigration status within the NYCHA were unavailable. Additional studies with more complete data on housing age, other locations, and high-risk subgroups are needed to confirm and extend our findings.

Public Health Implications

This study demonstrates the usefulness of electronic medical records for identifying and surveilling important public health issues and disparities. The NYC DOHMH is notified by laboratories of elevated BLLs in accordance with state and local health codes.[20] When such tests are performed on-site at a health center, health department notifications are facilitated by the use of electronic medical records. In the case of community health centers that serve vulnerable populations, use of electronic medical records can aid public officials in identifying and monitoring public health issues such as lead exposures. Valuable evidence from medical records can help define problem parameters and establish more effective public health interventions.[34] In communities with less robust local lead laws, electronic health records can be used in partnerships between community health centers and public health officials to identify lead problems and advocate for further regulation.

Our study also highlights the success of lead regulation policies in NYC. The decrease in elevated BLLs among all children since 2003 suggests the effectiveness of local legislation addressing lead exposures. Cities that do not have blanket local laws should consider passing local legislation to reduce lead exposures among children. The strict lead remediation standards that have successfully reduced lead exposures in the United States are urgently needed to protect children in other countries as well.[9]

Our findings and previous DOHMH data indicate that more than 40 000 children in NYC may have BLLs greater than 5 μg/dL.[23] Given the lifelong effects of lead exposures among children, NYC should continue to improve lead identification and reduce exposures, ideally before a child displays traces of lead in blood tests. A number of recent reports and public health advocates have focused on potential lead contamination and exposures among NYCHA residents. Our study suggests that children who live in NYCHA housing have a reduced risk of lead exposures. Whereas lead exposures in NYCHA housing should continue to be monitored and remedied, dissemination of our results can help prioritize lead exposure and remediation in private housing, especially in underserved neighborhoods. AJPH

CONTRIBUTORS

J. M. Chiofalo extracted data, completed the analyses, and led the writing. M. Golub and C. Crump assisted with the study and analyses. N. Calman originated and supervised the study.

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CONFLICTS OF INTEREST

We have no conflicts of interest to report.

HUMAN PARTICIPANT PROTECTION

This study was approved by the institutional review board of the Institute for Family Health.

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