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Who tests for lead and why? A 10-year analysis of blood-lead screening, follow-up, and CNS outcomes in a statewide U.S. healthcare system

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Abstract

Objectives.—Determine: (1) which providers in U.S.-healthcare systems order lead tests, why, and at what frequency, and (2) whether current patient-population lead-levels are predictive of clinical outcomes.

Methods.—Retrospective medical-record study of all blood-lead tests in Medical University of South Carolina healthcare system 2012–2016 and consequent evidence of CNS-related disease across a potential 10-year-window (2012–2022).

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Contributorship Statement

A. Reuben and R. Ward had full access to all study data and take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* A. Reuben, R. Ward, A.O. Rothbaum, M.G. Schmidt, D.G. Kilpatrick. *Acquisition of data:* A. Reuben, R. Ward, A.O. Rothbaum. *Analysis and interpretation of data:* A. Reuben, R. Ward, A.O. Rothbaum, M.G. Schmidt, A.J. Specht, D.G. Kilpatrick. *Drafting of the manuscript:* A. Reuben, R. Ward. *Critical revision of the manuscript for important intellectual content:* A. Reuben, R. Ward, A.O. Rothbaum, V.L. Cornelison, S. Huffman, L.M. McTeague, M.G. Schmidt, A.J. Specht, D.G. Kilpatrick. *Obtained funding:* D.G. Kilpatrick. *Administrative, technical, and material support:* V. Cornelison, S. Huffman, L.M. McTeague, M.G. Schmidt, A.J. Specht. *Study supervision:* D.G. Kilpatrick.

Research Ethics Approval

As a study of de-identified medical records designed to evaluate care practice, this study was determined by the MUSC Institutional Review Board to fall under a quality improvement designation exempt from ethics review.

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Results.—Across 4 years, 9,726 lead-tests resulted for 7,181 patients (49.0% female; 0–94 years), representing 0.2% of the hospital population. Most tests were for young (76.6% age 3) and non-Hispanic Black (47.2%) and Hispanic (26.7%) patients. A wide variety of providers ordered tests; however, most were ordered by pediatrics, psychiatry, internal medicine, and neurology. Lead-levels ranged from 2.0µg/dL (80.8%) to 10µg/dL (0.8%; max 36µg/dL). 201 children (3.1%) had initial lead-levels over the reference value for case-management at the time (5.0µg/dL). Many high-level children did not receive follow-up testing in the system (36.3%) and those that did often failed to see levels fall below 5.0µg/dL (80.1%). Non-Hispanic Black and Hispanic patients were more likely to see lead-levels stay high or go up over time. Over follow-up, children with high lead-levels were more likely to receive new ADHD and conduct disorder diagnoses and new psychiatric medications. No significant associations were found between lead-test results and CNS-diagnoses or medications among adults.

Conclusions.—Hospital lead-testing covers a small portion of patients but includes a wide range of ages, presentations, and provider-specialties. Lack of lead-decline among many pediatric patients suggests there is room to improve provider guidance around when to test and follow-up.

Keywords

Pediatric lead screening; Blood lead levels; ADHD; Health equity; Preventive medicine

Introduction

Lead is a neurotoxicant with a significant history of legacy contamination in the United States,(1,2) with on-going use in multiple industries. Potential exposures to lead – through contaminated products, soil, water, food, and dust in old homes – are a concern across the country, but are particularly problematic in urban, marginalized, and low-income communities with high rates of degrading lead-based water service lines, paints, telecommunication cables, and waste incinerator and lead-industry refuse.(3–5)

Even low-level lead exposure is believed to compromise child brain development(6) and adult mental,(7,8) cardiovascular,(9–11) and cognitive health.(12,13) The U.S.-Centers for Disease Control (CDC) recommend regular lead-exposure surveillance of children and pregnant women at-risk for exposure. In the absence of local surveillance programs “responsive to local conditions,” the CDC encourages “universal testing”(14) of blood-lead levels among children. The U.S.-Occupational Safety and Health Administration (OSHA) meanwhile requires regular testing of blood-lead levels among certain adults working in lead-related industries.(15)

Responsibility for U.S. lead-exposure surveillance is devolved to states, who report results to the CDC for nationwide compilation.(16) Within states, lead-testing is ordered by healthcare providers and offered by state public-health departments.(16–18) With three exceptions, decisions about when and how often to test for lead are left to the decision-making of individual healthcare providers. The first exception is for infants covered by Medicaid, who are required to receive blood-lead testing at 12- and 24-month well-visits. The second exception is for children living in one of 10 states and the District of Columbia that require universal testing at least once during an early-life well-visit (typically age 12-months or

24-months) and for children in one of 8 states with “targeted” testing requirements (typically for children living in “lead risk” areas with high poverty rates, older homes, and other risk factors).(19) The third is for adults working in lead-emitting industries who have been exposed to air-lead-levels above the “airborne action level” of $30\mu\text{g}/\text{m}^3$ for 30 days/year identified by air-quality testing.(15)

There are potential shortfalls in this system.(20–23) For the past decade, the average Medicaid lead-screening rate among 24-month-old children was only 67.4%.(24) Millions of children live in states without universal or targeted testing requirements. In such states, fewer than 10% of children are estimated to be routinely tested for lead(19) and up to 30% with high exposure may be missed.(23) For vulnerable adults (e.g., those >65 years) with potential non-occupational exposure, there are no state screening requirements or surveillance programs. Thus, it is not clear how many vulnerable individuals not covered by lead-testing may have potential exposure to lead. As the CDC notes, “blood lead testing is initiated by healthcare providers and it is difficult to know why or how healthcare providers decide to test.”(16)

This study aims to help fill this information gap by investigating lead-test results and follow-up care across a 10-year window (2012 to 2022) from a major academic healthcare system in the southeastern U.S. (the Medical University of South Carolina academic medical system, MUSC Health) serving residents from South Carolina and adjacent states, all of which lack universal or targeted testing requirements.

First, we document initial lead-test ordering in the MUSC medical-record system across a 4-year window (2012 to 2016) by healthcare provider type, patient demographics, and presenting diagnoses. Our goal was to determine “Who orders lead tests and why?” Second, we report rates of repeated lead-testing across the 4-year window to determine whether CDC and OSHA monitoring guidelines for pediatric and adult follow-up testing are being satisfied.

Third, we examine the medical-record for evidence of central nervous system-related disease (CNS) (developmental, psychiatric, degenerative) following initial lead-testing across a 10-year observation window (2012 to 2022) to determine whether lead-levels currently present in clinical populations are predictive of poor outcomes. We also test whether new CNS-medications are prescribed during the follow-up period. Results are interpreted to inform clinical guidelines for healthcare practitioners, who must decide when to order lead tests, and policymakers, who must decide where devolution of testing responsibilities is working.

Methods

Population

The study population included all individuals for whom a lead-test was ordered by a healthcare provider between June 17, 2012, and July 1, 2016, at MUSC Health. MUSC Health is a tertiary care system based in Charleston, South Carolina, with sites throughout the state that draw patients from across SC and neighboring Georgia and North Carolina. In

2022, MUSC had 751 care locations in SC, 2,500 in-patient hospital beds, 581 telehealth support sites, and >1million per-year patient encounters. Patients were included in the study if they had at least six months of in-system care prior to a first lead-test order to ensure baseline diagnoses and medications were observed such that new diagnosis and new medications outcomes could be accurately identified.

Lead testing and exposure

The exposure of interest was a lead-test-order in the medical-record and, secondarily, the lead-test result. The lead detection-limit available in the hospital system was 2.0µg/dL; results below this limit were marked '<2.0µg/dL.' Four exposure groups were established: none-low (<2µg/dL), medium (2 to <5µg/dL), medium-high (5 to <10µg/dL), and high (10µg/dL). No level of exposure is considered safe. During the study period the CDC recommended repeat testing for children within 3 months when lead-levels are 5–9µg/dL (changed to 3.5–9µg/dL in November 2021) and within 1 month for levels 10–19µg/dL. OSHA standards require semi-monthly testing until adult blood-lead levels are <40µg/dL. (15)

CNS disease

Primary outcomes of interest included the provider type requesting each lead-test and demographic variables for patients with test orders. Demographics included age (grouped by ages 0–3, 4–12, 13–17, 18–54, and 55 years), sex, race and ethnicity (Non-Hispanic Black, Hispanic, Non-Hispanic White, and Other or missing).

Secondary outcomes of interest included new CNS-related diagnoses and new CNS-related medications received / prescribed following a lead test for up to 10 years (June 18, 2012, to July 1, 2022). Given the large variety of diagnoses linked to patients with lead tests in the medical records, we investigated CNS-related diagnoses in broad domains separately for pediatric and adult patients. For patients under age 18 at the time of lead-testing, follow-up diagnoses were grouped by ICD-9-CM and ICD-10-CM codes into the broad domains of (1) neurodevelopmental conditions and (2) psychiatric conditions and the narrower sub-domains of (3) attention-deficit / hyperactivity disorder (ADHD) diagnoses and (4) conduct disorder diagnoses. For patients over the age of 18 at the time of lead testing, follow-up diagnoses were grouped into the broad domains of (1) psychiatric, (2) CNS-aging-related conditions (e.g., cognitive disorders), and (3) other CNS conditions (e.g., migraine, stroke), and the narrower psychiatric sub-domain of (4) substance use disorders. The broad and narrow domains were selected based on CNS-disease differences previously associated with lead exposure in other samples.(7,25–31) When a patient received multiple diagnoses over time that fell within a given domain, only the earliest occurrence was retained. Diagnoses that fell before the earliest lead-test were considered baseline diagnoses.

New medications were treated in a similar manner to new diagnoses. Medication domains included (1) psychotherapeutic and (2) other-CNS medications; these were identified based on the therapeutic classification variable included in the hospital's electronic health record (EHR) data system (Supplementary Table S1). Only medications prescribed at MUSC and recorded in the EHR were included.

Statistical Analysis

Summary statistics were used to compare patients by age and lead-exposure groups (<2, 2 to <5, 5 to <10, and $\geq 10\mu\text{g/dL}$) using chi-square tests, Fisher's exact tests, Wilcoxon rank-sum or t-tests, as appropriate. Follow-up analyses among patients with high baseline lead-levels compared those with repeat lead testing who demonstrated flat or positive test-result slopes (e.g., lead levels did not improve during surveillance) to those with negative slopes. Next, associations of lead exposure levels with new CNS diagnoses or medications during the follow-up window were estimated using generalized linear models with general estimating equations (GEE). Multiple lead-test results per patient were accounted for using the Repeated statement in SAS PROC GENMOD (SAS Institute Inc., Cary, NC). Results are reported as odds ratios (OR) with corresponding 95% confidence intervals (CIs). Significance tests were two-tailed, $\alpha=0.05$. This report follows RECORD reporting guidelines.

Results

Who orders and receives lead tests?

Table 1 presents summary statistics for patients who received lead-testing. Across the 4-year study-window (2012–2016), 9,726 lead-test orders resulted for 7,181 patients (49.0% female; ages 0–94 years), reflecting 2,133 patients (29.7%) who received multiple tests. Most tests were ordered for pediatric patients (76.6% were aged ≤ 3 years) and for non-Hispanic Black (47.2%) and Hispanic (26.7%) patients.

Table 2 presents provider-type for lead-test orders by patient age. Lead-test orders came primarily from pediatrics providers for patients aged 0–12 years, from psychiatry providers for patients aged 13–17, and internal medicine, neurology, and psychiatry providers for adult patients (≥ 18 years).

Supplementary Table S2 presents the most common principal diagnoses for visits with initial lead-tests orders. For children ≤ 12 years, routine immunizations and well-visits were the most common “diagnoses” used for visit billing, with “screening for chemical poisoning,” anemia, foster-care status, and ADHD as the next most common diagnoses. For children ages 13–17, psychiatric diagnoses (unspecified psychosis, suicidal ideation, “anxiety state,” and depressive disorder) were most common, with anemia, ADHD, and health-checks the next most common. Among adults aged 18–54, diagnoses were primarily for psychiatric symptoms (substance use disorder, anxiety, malaise and fatigue) and hypertension. Among adults age ≥ 55 , hypertension, hyperlipidemia, and “other malaise and fatigue” were most common.

Do lead follow-up testing rates match guidelines?

Initial lead-test results in the full patient-population ranged from below the detection limit of $2.0\mu\text{g/dL}$ (80.8% of patients) to $10\mu\text{g/dL}$ (0.8% of patients) (Figure 1). As shown in Supplemental Table S3, there were lead-differences by gender and race and ethnicity among pediatric patients but not adults (who were a substantially smaller group). Pediatric males were more likely to have baseline results between 2 and $10\mu\text{g/dL}$, while pediatric females

were more likely to have results $\geq 10\mu\text{g/dL}$ ($p=0.022$). Pediatric non-Hispanic Black patients were substantially more likely to have lead test results in all detectable categories ($\geq 2\mu\text{g/dL}$ and above) compared to other groups ($p<.0001$).

There were 201 pediatric patients (3.1%) with initial lead-test results over the reference value for case-management action at the time of testing ($5.0\mu\text{g/dL}$) and 362 (5.6%) with results over the current reference value ($3.5\mu\text{g/dL}$) (Table 1). No adults tested over the OSHA-clinical target for repeat testing of $40\mu\text{g/dL}$.

Overall, 2,133 patients received repeated lead testing, of whom 90.7% had a result below the detection limit at every test. Of the 201 pediatric patients with initial lead test scores $\geq 5.0\mu\text{g/dL}$, only 128 (63.7%) received one or more follow-up tests in the MUSC system. Figure 2 presents the trajectories for the 160 pediatric patients with repeated testing for whom initial or final results were $\geq 5\mu\text{g/dL}$; all were age ≥ 3 at initial testing. Within this group, 44 (27.5%) had flat or positive slopes (i.e., blood-lead levels did not decline) and 60 (37.5%) had final scores above $5\mu\text{g/dL}$ (i.e., follow-up was terminated before lead-levels fell below reference value). Non-Hispanic Black and Hispanic patients were much more likely to experience flat or positive slopes than non-Hispanic White patients (35.0% for Black and 25% for Hispanic patients compared to 4.8% for non-Hispanic White patients, $p=0.011$). Non-Hispanic Black and Hispanic patients were also much more likely to have test scores $\geq 5\mu\text{g/dL}$ at their final test (45.0% and 35.7%, respectively) compared to non-Hispanic Whites (14.3%), $p=0.03$.

Are lead-test scores predictive of greater CNS disease during follow-up?

Diagnoses.—35.4% of lead-tested pediatric patients received a new CNS-disease diagnosis during the study timeframe; 17.7% received a new diagnosis within one year. Table 3 presents results from models estimating the association of blood-lead values with subsequent risk for a new CNS diagnosis. These models, all adjusted for sex, age group, and race and ethnicity, produced mixed findings (full model results found in Supplemental Table S4; Supplemental Table S5 reports counts of new diagnoses over follow-up for patients at each level of lead-test score). In comparison to pediatric patients with low lead-levels ($<2\mu\text{g/dL}$) those with moderate levels ($\geq 2\mu\text{g/dL}$ to $<10\mu\text{g/dL}$) were not more likely to receive any new developmental or psychiatric disorder diagnosis *writ large* ($p=0.8$ and $p=0.9$, respectively). However, they had more than 20% greater risk for specific diagnoses in the narrower domains of ADHD and conduct disorder (HR's of 1.22 and 1.37, respectively, p -values $<.05$). Children with the highest lead values ($\geq 10\mu\text{g/dL}$) had more than twice the risk of receiving an ADHD diagnosis over follow-up compared to low-level peers (HR: 2.08, 95%CI: 1.37, 3.15); results for other diagnosis categories were not significant, although hazard ratios were greater than 1.0 in all cases, suggesting a possible trend towards association in this smaller high exposure group (only 65 of 6,505 pediatric patients had any test result $\geq 10\mu\text{g/dL}$).

Among adult patients, 73.6% received a new CNS-disease diagnosis during the study timeframe; 48.6% received a new diagnosis within one year of lead testing. No significant associations between higher lead-test results and new diagnoses were found in the adult group (Table 3).

Medications.—Among pediatric patients, 16.1% received new medications during the study timeframe, of which 14.1% were psychotherapeutic medications and 4.0% were CNS-related (e.g., for migraine). Table 3 present results from models testing the association of initial blood-lead levels with risk for a subsequent new psychotherapeutic or CNS-related medication. (Supplemental Table S5 reports counts of new medications over follow-up for patients at each level of lead-test score). Similar to the models for new diagnoses, these were adjusted for sex, age group, and race and ethnicity, and again produced mixed findings.

In comparison to pediatric patients with low lead-levels (<2µg/dL) those with moderate levels (2µg/dL to <10µg/dL) were more likely to receive new psychotherapeutic or other CNS medications over time (HR=1.21, 95%CI: 1.02, 1.44, p=0.03). Among the highest exposure group (≥10µg/dL) results did not reach significance (HR=1.83, 95%CI: 0.82, 4.1, p=0.14), potentially due to the small number of patients in the category (N=94). There was also a trend towards significance for receipt of psychotherapeutic medications among pediatric patients with moderate and high lead-levels (p-values=0.06 and 0.11, respectively).

Among adult patients, 73.5% received new medications during the study timeframe, of which 65.2% were psychotherapeutic medications and 45.6% were CNS-related. No significant associations between higher lead-test results and new medications were found in the adult group (Table 3).

Discussion

This retrospective medical record study generated five primary findings. First, the lead-testing rate at a major tertiary academic-healthcare center in the southeastern U.S. (MUSC Health) was just over 2,400 tests a year for approximately 1,800 patients. This represents approximately 0.2% of the patient encounters seen each year at MUSC and 0.04% of the 5.2 million residents of South Carolina. The majority of tests were ordered for populations of concern, including children 3 years (76.6% of test orders) and for non-Hispanic Black and Hispanic patients (47.2% and 26.7% of test orders, respectively).

Second, provider specialties found to order lead-tests varied by patient age. Appropriately, pediatrics was most likely to order lead-tests for pre-adolescent patients, psychiatry for adolescent patients, and internal medicine for adults. Lead-test orders were not restricted to these specialties, however: neurology, oncology, gastroenterology, cardiology, family medicine, and emergency medicine also requested lead-tests, albeit at low rates. In an effort to reach more at-risk patients with lead surveillance, future research could utilize mixed methods (e.g., surveys, focus groups) to determine what training about lead risks these specialties receive and what motivates less-common specialties to order tests.

Notably, past surveys (now three-decades old) of pediatricians(32) and pediatric residents(33) identified sex, regional, and practice-setting-based differences in provider lead-test ordering in an era when CDC guidelines called for universal screening of children under age 6. Pediatrics providers who were male, practicing in suburban and rural areas, and living in the South or West were less likely to follow universal screening guidelines. Those who had graduated from medical school more recently (<10 years) were more likely

to universally screen, as were those who had read the CDC guidance and believed that their state required testing.(32,33) While no surveys of lead testing beliefs or motivations have been conducted among other provider specialties to the best of our knowledge, evidence suggests that state testing requirements, guidance from government agencies, and training / guidelines from professional associations may significantly increase provider test ordering, particularly for higher risk patients.(32,33)

Why are lead-tests ordered? One answer lies in the diagnoses that accompany lead-test orders. For young pediatric patients these included, appropriately, health-checks, “screening for chemical poisoning,” anemia, and ADHD, and, for older pediatric patients, psychiatric diagnoses. These diagnoses suggest that pediatric providers are aware of the extensive body of evidence linking lead to these specific conditions.

Diagnoses most likely to accompany adult lead-test orders included primarily psychiatric diagnoses, malaise and fatigue, and, in adults aged 55 and older, hypertension and hyperlipidemia. In this regard, the emerging evidence linking low-level lead exposure to cardiovascular disease (CVD), particularly coronary heart disease, warrants specific mention. While heart disease was not evaluated in this CNS-focused study, lead has recently been identified by the American Heart Association as a “significant contributor” to CVD worldwide,(11) with specific lead-related differences in arterial stiffness, blood pressure, lipid metabolism, inflammation, and endothelial function identified in mechanistic studies.(11) Epidemiologic evidence has, meanwhile, linked adult blood-lead levels to excess CVD morbidity and mortality in multiple studies in the U.S., Europe, and Asia. (9–11) Notably, while hypertension and hyperlipidemia were the diagnoses most likely to accompany lead tests orders in adults aged 55 and over in this study, such tests were rarely ordered by cardiology providers, who only ordered 12 lead tests in total over the 4-year observation window (representing 1.8% of all adult lead test orders). Lead-associated risk for adult bone(34) and kidney(35) disease was likewise under-represented in the ordering-provider specialties. Finally, a lack of diagnoses related to cognitive conditions and dementing illnesses suggests that lead exposure, a putative risk for neurodegenerative disease,(12,13,36) is not yet “on the radar” of geriatricians, at least in this investigated medical system.

Third, one fifth of patients (19.2%) had blood-lead levels above the detection limit of 2.0µg/dL. This matches national blood-lead level rates in the U.S. during the study period(37) and indicates that lead exposures were, as anticipated, on-going in the wider South Carolina community. Among pediatric patients, 3.1% of tested children exceeded the previous reference value (5µg/dL) and 5.2% exceeded the current reference value (3.5µg/dL). These lead-level rates match those reported by South Carolina’s child-lead-tracking program, which reported elevated pediatric lead-level rates from 3% to 4% depending on the year of study.(38) SC-state tracking indexed between 15,000 and 20,000 pediatric lead-tests statewide on average during the study period – an approximate 4% statewide pediatric lead-screening rate.(38) No study adults tested over the OSHA clinical target of 40µg/dL.

Fourth, one third of children (36.3%) with elevated blood-lead levels failed to receive follow-up testing during the study window, at least within the MUSC system. For children

with elevated levels that did receive follow-up testing within MUSC: one fourth (27.5%) had flat or positive lead-test slopes, indicating a failure lead abatement; one third (37.5%) had final scores above the reference value, indicating a failure of follow-up to extend until lead abatement was successful. Non-Hispanic Black and Hispanic patients were significantly more likely than non-Hispanic White patients to experience these negative outcomes. Future work should investigate where in the chain of care improvements can be made to promote health equity. As noted below, it is possible that children received additional testing outside MUSC Health (e.g., at public health departments), which should be taken into account in future investigations.

Fifth, in confirmation of past studies on lead exposure implications for brain development, (6,39,40) children with detectible lead-levels were more likely to receive new developmental and psychiatric diagnoses as well as new related medications across up to 10 years of follow-up. Specifically, children with moderate lead levels ($2\mu\text{g}/\text{dL}$ to $<10\mu\text{g}/\text{dL}$) were 22% and 37% more likely to receive new ADHD and conduct disorder diagnoses, respectively, and 21% more likely to receive new psychotherapeutic or CNS-related medications. In comparison to children with levels at or below the detection limit, children with the highest lead-levels ($\geq 10\mu\text{g}/\text{dL}$) had twice the risk of later receiving an ADHD diagnosis. No statistically significant associations between higher lead-test results and new diagnoses or medications were found among adult patients, a finding that may reflect the relatively small number of adults who received lead testing during the study window (i.e., positive point estimates did not achieve significance owing to wide confidence intervals). While study results are observational and cannot establish causation, lead is believed to elevate rates of neurodevelopmental and psychiatric conditions through a variety of brain and non-brain-based mechanisms that diminish emotional- and behavioral-regulation capacity, including neuroinflammation, abnormal brain-derived neurotrophic factor (BDNF) expression, mitochondrial dysfunction, and oxidative stress.(6)

This study has limitations. First, as noted above, we do not know what decision-making contributed to provider lead-test ordering. Future studies should consider mixed methods to approach this question. Second, we do not know whether specific lead abatement case-management interventions followed test results. Third, it is possible that patients received additional lead testing after the observation window at public health departments or other health systems. Future studies could extend the observation window to confirm current results and incorporate multiple health systems where possible. Fourth, blood-lead tests are a measure of acute exposure (across the proceeding 4–6 weeks) and cumulative exposure across time was unknown. Future studies should consider the potential utility of cumulative, bone-lead assessments among high-risk patients. Fifth, this study considered only one population living in one region of the U.S who received care at one care system; results should be replicated in other hospital systems, regions, and countries. Sixth, the study is based solely on data from the electronic medical record, which may not capture all relevant information, including family or patient home or occupational information that could be used to identify potential routes of lead exposure, or information about other exposures that can influence the CNS (e.g., mercury, polycyclic aromatic hydrocarbons, etc.). Finally, the study was observational and cannot establish causation.

Conclusions

While lead exposure rates continue to decline in the U.S. and other countries,(2,3) lead remains a hazard for both children and adults.(2,5,23) In one major southeastern healthcare system investigated across the past 10 years, we determined that lead testing covered only a small portion of the hospital population but nevertheless represented a wide range of patient ages, presentations, and provider specialties, from pediatrics and psychiatry to neurology and oncology. Often, pediatric patients found to have blood-lead levels above reference values for case management did not experience improvements, with lead monitoring proving either unsuccessful, unrepeated, or terminated prematurely. Often, pediatric patients with elevated lead-levels went on to experience deteriorations in their health, as identified by new developmental and psychiatric diagnoses and the use of new related medications.

In many U.S. states, responsibility for lead testing is delegated to individual healthcare providers. There remains room for improvement in the systems guiding provider decision-making around when to test and how to follow-up on positive results.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data Availability

Study data is available to qualified researchers upon reasonable request.

Abbreviations.

ADHD	Attention Deficit / Hyperactivity Disorder
CDC	Centers for Disease Control
CNS	Central Nervous System
MUSC	Medical University of South Carolina
OSHA	Occupational Safety and Health Administration
US	United States

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Key Message**What is already known on this topic.**

Lead is a widely distributed toxicant present in older homes, soils, and certain foods. Decisions about when to test patients for lead often fall to individual healthcare providers, but it is not clear whether current testing decisions match guidelines or patient need.

What this study adds.

Across years in a major US-hospital system, only 0.2% of patients were tested for lead each year, although testing represented a wide range of patients ages, presentations, and provider-specialties. Many high lead-level pediatric patients did not receive follow-up testing in the system (36.3%) and those that did often failed to see levels fall below reference values (80.1%). Non-Hispanic Black and Hispanic patients were more likely to see lead-levels stay high or go up over time.

How this study might affect research, practice or policy.

Lack of lead-testing among elderly patients and lead-decline among many pediatric patients suggests there is room to improve provider guidance around when to test and follow-up.

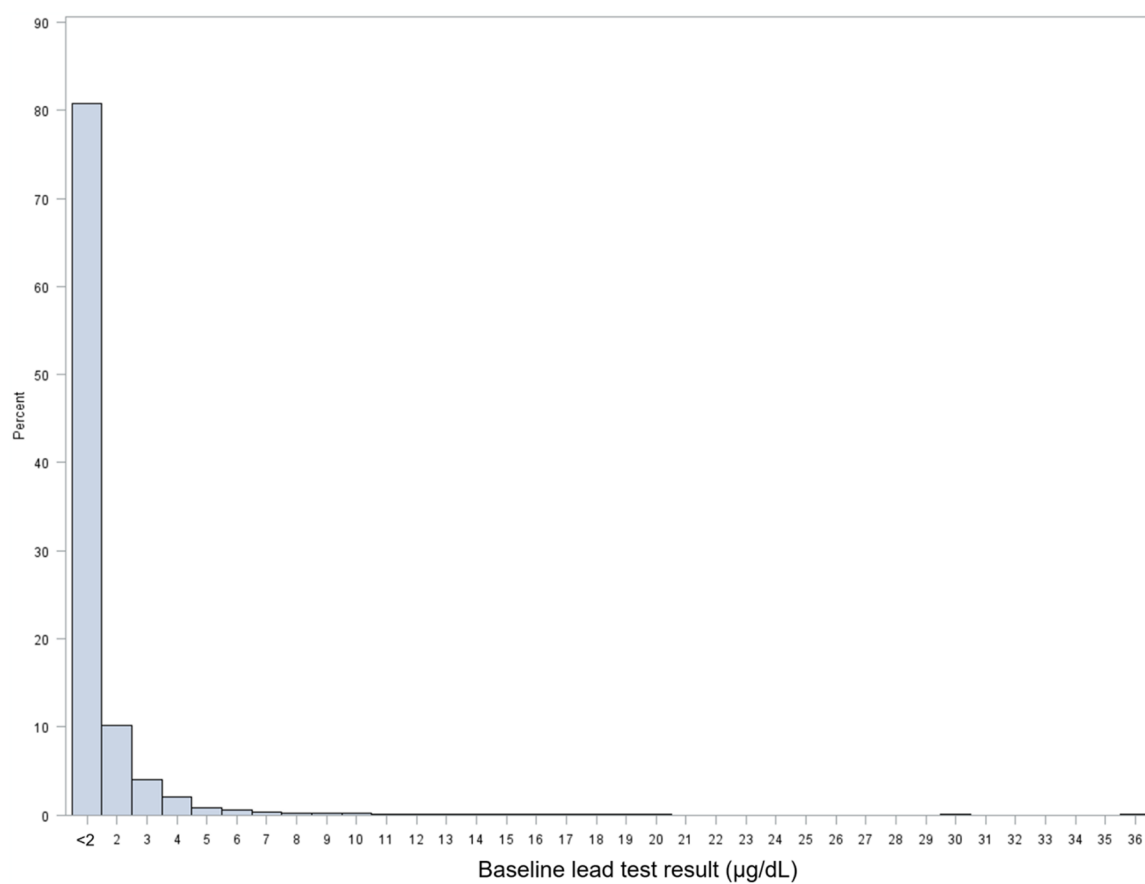


Figure 1. Distribution of initial lead test scores (blood-lead levels) across the Medical University of South Carolina healthcare system from 2012 to 2016.

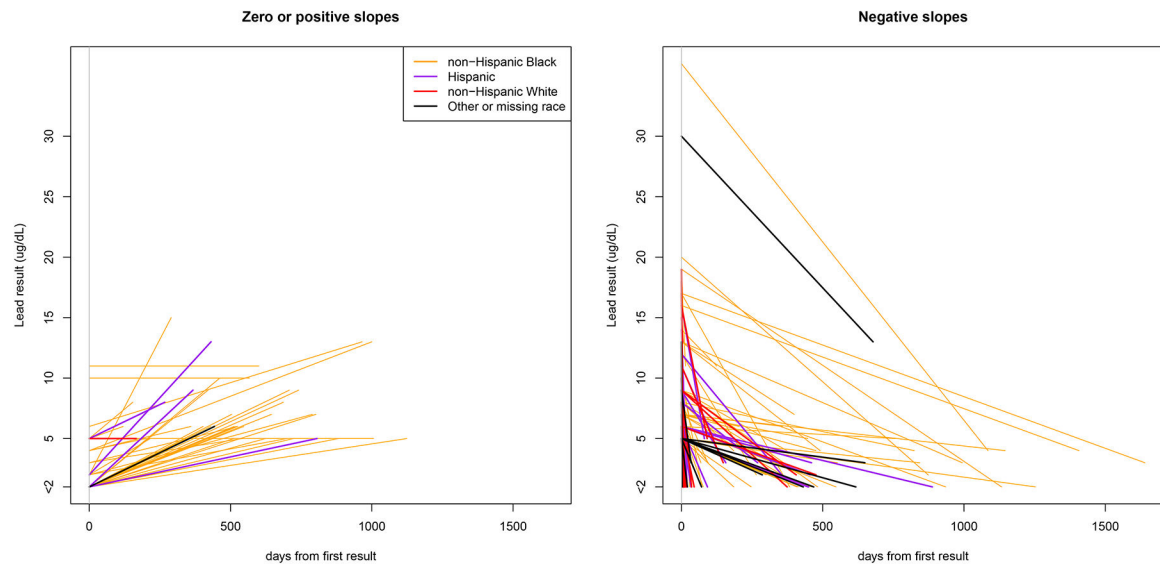


Figure 2.

Blood-lead level trajectories for the 160 pediatric patients with baseline or final tests above the reference value ($5\mu\text{g/dL}$).

Panel A. Patients with flat or increasing lead levels across follow-up, by race and ethnicity

Panel B. Patients with declining lead levels across follow-up, by race and ethnicity

Figure presents lead-test score intercepts and slopes for the 160 pediatric patients with repeated testing for whom initial or final results were above the reference value ($5\mu\text{g/dL}$); all were aged 3 or younger at baseline testing. All depicted trajectories are linear as, for clarity, only first and final results are shown. Within this group, 44 children (27.5%) had flat or positive slopes (i.e., blood-lead levels did not decline) and 60 (37.5%) had final scores above $5\mu\text{g/dL}$ (i.e., follow-up was terminated before lead-levels fell below reference level).

Table 1.

Demographic details of patients with lead test orders during the 4-year test observation window (2012 to 2016).

Demographic variable	Level	Patient age					Row total
		0–3 years	4–12 years	13–17 years	18–54 years	55 years	
Group size <i>N</i> (%)		5,502 (76.6%)	831 (11.6%)	175 (2.4%)	334 (4.7%)	339 (4.7%)	7,181
Sex , <i>N</i> (% <i>by age group</i>)							
	Female	2,702 (49.1%)	393 (47.3%)	99 (56.6%)	165 (49.4%)	160 (47.2%)	3,519 (49%)
	Male	2,800 (50.9%)	438 (52.7%)	76 (43.4%)	169 (50.6%)	179 (52.8%)	3,662 (51%)
Race and ethnicity , <i>N</i> (% <i>by age group</i>)							
	Hispanic	1,703 (31%)	187 (22.5%)	18 (10.3%)	6 (1.8%)	3 (0.9%)	1,917 (26.7%)
	Non-Hispanic Black	2,673 (48.6%)	448 (53.9%)	83 (47.4%)	102 (30.5%)	82 (24.2%)	3,388 (47.2%)
	Non-Hispanic White	782 (14.2%)	134 (16.1%)	63 (36%)	218 (65.3%)	246 (72.6%)	1,443 (20.1%)
	Other or missing	344 (6.3%)	62 (7.5%)	11 (6.3%)	8 (2.4%)	8 (2.4%)	433 (6.0%)
Baseline blood-lead level , <i>N</i> (% <i>by age group</i>)							
	5.0 µg/dL	172 (3.1%)	28 (3.4%)	1 (0.6%)	4 (1.2%)	14 (4.1%)	219 (3.1%)
	3.5 µg/dL	287 (5.2%)	48 (5.8%)	1 (0.6%)	5 (1.5%)	21 (6.2%)	362 (5.0%)
Repeat lead testing , <i>N</i> (% <i>of patients by age group with repeated testing</i>)	Repeat tests	2,046 (37.2%)	45 (5.4%)	8 (4.6%)	17 (5.1%)	17 (5%)	2,133 (29.7%)

Table 2.

Provider types ordering lead tests, by specialty and patient age.

Panel A. Pediatric patients					
Patient ages 0 – 3 (N=5,502)			Ages 4–12 (N=831)		Ages 13–17 (N=175)
Authorizing provider	N (%)	Authorizing provider	N (%)	Authorizing provider	N (%)
PEDIATRICS	4,139 (75.2%)	PEDIATRICS	526 (63.3%)	PSYCHIATRY	74 (42.3%)
PEDIATRIC ORTHO.SURG.	334 (6.1%)	PEDIATRIC ONCOLOGY	47 (5.7%)	PEDIATRICS	47 (26.9%)
INTERNAL MEDICINE	281 (5.1%)	NURSE PRACTITIONER	42 (5.1%)	NURSE PRACTITIONER	21 (12%)
NURSE PRACT.	227 (4.1%)	PEDIATRIC ORTHO. SURG.	42 (5.1%)	PEDIATRIC GASTROENT.	9 (5.1%)
PEDIATRIC ONCOL.	139 (2.5%)	INTERNAL MEDICINE	37 (4.5%)	PEDIATRIC EMERG.MED.	7 (4%)
FAMILY MEDICINE	112 (2%)	FAMILY MEDICINE	35 (4.2%)	PEDIATRIC NEUROLOGY	5 (2.9%)
		PSYCHIATRY	34 (4.1%)	FAMILY MEDICINE	3 (1.7%)
		PEDIATRIC GASTROENT.	15 (1.8%)	INTERNAL MEDICINE	2 (1.1%)
		PEDIATRIC NEUROLOGY	11 (1.3%)		

Panel B. Adult patients					
Ages 18–54 (N=334)			Ages 55 (N=339)		
Authorizing provider	N (%)	Authorizing provider	N (%)	Authorizing provider	N (%)
INTERNAL MEDICINE	81 (24.3%)	INTERNAL MEDICINE	137 (40.4%)		
NEUROLOGY	72 (21.6%)	NEUROLOGY	91 (26.8%)		
PSYCHIATRY	53 (15.9%)	FAMILY MEDICINE	23 (6.8%)		
FAMILY MEDICINE	30 (9%)	PSYCHIATRY	20 (5.9%)		
EMERGENCY MEDICINE	11 (3.3%)	PULMONARY DISEASE	8 (2.4%)		
OBSTETRICS AND GYNEC.	8 (2.4%)	CARDIOLOGY	7 (2.1%)		
HEMATOLOGY AND ONCOL.	7 (2.1%)	EMERGENCY MEDICINE	5 (1.5%)		
NEUROSURGERY	6 (1.8%)	GASTROENTEROLOGY	5 (1.5%)		
PULMONARY DISEASE	6 (1.8%)	ANESTHESIOLOGY	4 (1.2%)		
CARDIOLOGY	5 (1.5%)	NEUROSURGERY	4 (1.2%)		
GASTROENTEROLOGY	5 (1.5%)				
HOSPITALIST	5 (1.5%)				

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Panel B. Adult patients			
Ages 18–54 (N=334)		Ages 55 (N=339)	
Authorizing provider	N (%)	Authorizing provider	N (%)
RHEUMATOLOGY	5 (1.5%)		
NEPHROLOGY	4 (1.2%)		

Table 3.

Associations of blood-lead values with risk for new CNS disease during the 10-year observation window.

Panel A. Pediatric patients (N=6,508 patients)				
	Lead test result (ref= <2µg/dL, N=7,092 tests)			
	2 to < 10µg/dL (N=1,821)		10 µg/dL (N=94)	
New Diagnoses	HR (95% CI)	p-value	HR (95% CI)	p-value
Broad disorder domains				
Developmental disorders	1.02 (0.87, 1.2)	0.80	1.16 (0.81, 1.66)	0.42
Psychiatric disorders	0.99 (0.8, 1.21)	0.91	1.26 (0.75, 2.1)	0.38
Narrow disorder domains				
ADHD	1.22 (1.01, 1.47)	0.04	2.08 (1.37, 3.15)	<0.001
Conduct / antisocial problems	1.37 (1.06, 1.77)	0.02	1.11 (0.49, 2.48)	0.80
New Medications	HR (95% CI)	p-value	HR (95% CI)	p-value
Broad domains				
New psychotherapeutic or other CNS medication	1.21 (1.02, 1.44)	0.03	1.83 (0.82, 4.1)	0.14
Narrow domains				
Psychotherapeutic medications	1.18 (0.99, 1.39)	0.06	1.99 (0.86, 4.58)	0.11
Other CNS medications	1.02 (0.77, 1.36)	0.86	0.69 (0.17, 2.76)	0.60
Panel B. Adult patients (N=673)				
New Diagnoses	Lead test results < 2 µg/dL (N=552) vs. 2 µg/dL (N=147)			
	HR (95% CI)		p-value	
Broad disorder domains				
Age-related cognitive disorders	1.26 (0.64, 2.48)		0.50	
Psychiatric disorders	0.98 (0.58, 1.67)		0.96	
Other CNS conditions	1.38 (0.86, 2.22)		0.18	
Narrow disorder domains				
Substance use disorders	1.53 (0.72, 3.24)		0.27	
New Medications	HR (95% CI)		p-value	
Broad domains				
New psychotherapeutic or other CNS medications	1.13 (0.76, 1.69)		0.54	
Narrow domains				
Psychotherapeutic medications	1.08 (0.72, 1.61)		0.71	
Other CNS medications	0.81 (0.53, 1.23)		0.32	

Note. Analyses adjusted for sex, age group, and race and ethnicity.