## 7. EFFECTS OF LEAD EXPOSURE

### Definitions

Lead is a soft, dense, ductile blue-gray metal.[254] Due to its properties, its use has been common for centuries and greatly increased with the Industrial Revolution. According to a World Health Organization report, "the widespread occurrence of lead in the environment is largely the result of human activity, such as mining, smelting, refining and informal recycling of lead; use of leaded petrol (gasoline); production of lead-acid batteries and paints; jewelry making, soldering, ceramics and leaded glass manufacture in informal and cottage (home-based) industries; electronic waste; and use in water pipes and solder."[255]

The decline in childhood blood lead levels has been primarily due to major policy decisions, including the ban on lead in gasoline that was fully implemented in the US by 1996, removal of lead solder from food cans, and the ban on lead paint that was fully implemented in 1978.[256] However, lead from previous uses persists in the environment. For most children in the United States, the main source of exposure is deteriorating lead-based paint in older, poorly maintained homes.  Lead from the paint becomes part of the dust in the home which children may then ingest as part of hand to mouth behaviors.[257] Adults and other children in the same environment may not be exposed unless dust is generated through renovation or repair work.[258]

Other potential sources of lead in a child's environment derive from its previous use as an additive in gasoline, in plumbing, and in imported products contaminated with lead.[259] The ban on lead in gasoline was fully implemented in the US by 1996, and had led to significant declines in blood lead levels. However, lead in soil is in part due to its past use and can still be a source of exposure for children when they play outdoors or when the outdoor soil contributes to lead dust indoors.[260] Lead solder use for plumbing was eliminated by 1988, and public drinking water systems are now required to monitor for lead and to implement measures to decrease water corrosivity to prevent the leaching of lead from the pipes into the water.[261,262] However, exposure can and does still occur through water systems that are more than 20 years old and that use acidic water, which may cause corrosion of lead in the pipes.[263] Other sources of lead exposure in the US are imported items that can include clay pots, candy, make-up, jewelry, and home remedies.[264]

Children are more vulnerable to lead poisoning than adults because they are more likely to have hand to mouth behavior after contact with contaminated surfaces, such as deteriorating paint from walls in their homes. Furthermore, children absorb larger fractions of ingested lead than adults, and their developing nervous system is especially susceptible to lead toxicity. Children can be exposed to lead prenatally, absorbing the lead contained in their mother's body, or environmentally by drinking contaminated water or swallowing or breathing lead in dirt, dust, or sand while they play on the floor or ground. Children with significant lead poisoning may develop anemia, kidney damage, abdominal pain, muscle weakness, brain damage, seizures, coma, and even death. Fetuses exposed to lead in the womb may be born prematurely and have lower weights at birth. Even at low levels of exposure and without other clinical symptoms, lead can affect a child's mental and physical growth, and his or her ability to thrive.[265,266,267]

Blood lead measurement is the primary screening method for lead exposure. Blood lead measurement is a reliable, inexpensive and readily available method.  Although it is a reflection of recent exposure, methods that more accurately reflect overall body lead burden, such as bone x-ray techniques, are not widely available.[268] The CDC and other public health agencies have published guidance for the interpretation of blood lead results, all with the understanding that no safe blood lead level (BLL) in children has been identified. To address this and to encourage the implementation of primary prevention interventions (i.e. preventing exposures before they occur), the CDC moved from using the term "level of concern" which was defined as BLLs ≥10 µg/dL in 1991 to use of the term "reference level" defined as 5 µg/dL in 2012. The reference level of 5 µg/dL is used to identify children with blood lead levels that are significantly higher than most children's levels. This new level is based on the U.S. population of children aged 1 to 5 years who are in the highest 2.5% of children when tested for lead in their blood.[269]

### Prevalence

Based on national 2007 to 2010 data analyzed in a CDC report, about 2.6% of children aged 1 to 5 years have blood lead levels at or above the reference value of 5 µg/dL, which is an estimated 535,000 children. According to CDC data, black children had significantly higher mean Blood Lead Levels than white or Mexican American children. Mean blood lead levels were also higher in children enrolled in Medicaid, compared to those with private insurance. The CDC report concludes that the differences in the mean blood lead levels across the different race, ethnicity and income groups arise from differences in housing quality, environmental conditions, nutrition, and other factors.[270]

Data at the local level show considerably higher prevalence rates for some vulnerable communities. In Detroit in 2012, 8.5% of children under 6 years old who were tested had high blood lead levels (>= 5ug/dL).[271] In Providence, Rhode Island, a study on children attending public kindergarten where more than 90% of students qualified for the federal free or reduced-price school lunch program, 69% had at least 1 previously reported BLL that was high (>= 5ug/dL).[272]

Lead-based paint hazards are the primary source of childhood exposure to lead in the US.[273] Of an estimated 16.8 million homes with children under the age of 6, 3.6 million homes (21%) have lead-based paint hazards, based on 2005-2006 data. In 5.8 million households earning less than $30,000 per year with children under age 6, 1.1 million (20%) have lead-based paint hazards. [274]

The situation in the city of Flint, Michigan has brought water-borne lead exposure back to public attention, after a 2014 change in the city water system dramatically increased the levels of lead in drinking water. The number of children with elevated blood lead levels increased from 2.6% to 4.9% for the entire city of Flint and from 4.0% to 10.6% in the most affected area, compared to a non-significant increase from 0.7% to 1.2% outside the city in the same time period. [275]

### Unmet need for services

The critical 'intervention' for lead poisoning is actually primary prevention—preventing it from happening in the first place through mitigation or elimination of environmental. Blood lead screening provides critical information that can be used to guide interventions for individual patients, and provides critical data to guide population level primary prevention efforts. Children who have been exposed to lead often have other challenges to learning and behavior, and lead poisoning may only be one of the factors influencing those outcomes. If those others factors can be modified, and special effort made to enrich the intellectual development of the child, the detrimental effects can potentially be overcome.[276]

The duration and effects of lead poisoning when children are exposed can be minimized through screening, early identification, and removal of the source of exposure. The Bright Futures guidelines, adopted by the American Academy of Pediatrics (AAP) in 1998 and endorsed by the Health Resources and Services Administration (HRSA), recommend that a clinical risk assessment for lead exposure be performed for infants (at ages 6 and 9 months and annually from the ages of 1 to 6 years), with blood lead testing to follow if positive. The Bright Futures guidelines also recommend that children who receive services from public assistance programs (e.g. Medicaid) or live in a high-risk area should be screened at 12 and 24 months. The AAP, in its policy statement on lead exposure in children, recommends that pediatricians measure blood lead concentrations in Medicaid-eligible children in accordance with state Medicaid regulations, apply guidance from city or state health department about screening children not eligible for Medicaid, and if there is none, consider screening all children.[277] Because lead risk varies across the United States, CDC lead screening recommendations request state and local health departments to use local data on lead risks as the basis for developing lead screening recommendations for health-care providers that target children at risk in their areas, focusing on children aged 1 to 2 years.[278] In 2012, the Centers for Medicare and Medicaid Services revised its policy on screening Medicaid eligible children for lead poisoning to align with the CDC recommendation of adopting targeted screening in states that have sufficient data to demonstrate that universal screening is not the most effective method of identifying exposure to lead. CDC and CMS have developed criteria and guidance that States should consider when requesting to shift to a targeted screening plan for individuals covered by Medicaid. CDC and CMS will review the information provided to determine if it is sufficient to support the State's request.[279]

Despite these recommendations, an analysis conducted by the Centers for Medicare and Medicaid Services indicated that approximately 67% of Medicaid-enrolled children aged 2 years were tested for lead by their second birthday during 2014,[280] potentially missing opportunities to identify and mitigate the risk of permanent neurologic damage and behavioral disorders in hundreds of thousands of young children across the United States.

**Impact on Learning**

The bulk of the scientific literature indicates that there are persistent and deleterious effects of environmental lead exposures on a variety of outcomes related to the ability to learn, such as decreased IQ, diminished school performance, and behavioral problems. While in 2012 the CDC changed the definition of high blood lead level to lead level at or above 5 μg/dL[281] (lowering the threshold from the previous one of 10 μg/dL),[282] the majority of the examined studies on learning-related outcomes were conducted prior to 2012 and therefore describe blood lead levels as below or above the 10 μg/dL. What follows is a summary of findings organized by learning outcome.

*Decreased IQ*

Increases in blood lead levels have been shown to be associated with significant decreases in IQ. A systematic review of 26 studies that collects evidence from 1979 to 1994 concludes that the great majority of the studies examined showed an inverse association between lead and IQ, with the overall synthesis of the evidence indicating that a typical doubling of body lead burden (from 10 to 20 micrograms/dl blood lead or from 5 to 10 micrograms/g tooth lead) is associated with a mean deficit in full scale IQ of around 1-2 IQ points.[283]

In a study on internationally pooled data, the estimated IQ decrements associated with an increase in blood lead from 2.4 to 10 μg/dL, 10 to 20 μg/dL, and 20 to 30 μg/dL were 3.9, 1.9, and 1.1, respectively. The study also concluded that there is evidence of lead-related intellectual deficits among children who had maximal blood lead levels < 7.5 μg/dL, and that indeed there is no evidence of a lower threshold for harmful blood lead levels.[284]

These results are in line with that of a study conducted by the University of Rochester, that found that each increase of 10 μg per deciliter in the lifetime average blood lead concentration was associated with a 4.6-point decrease in IQ, whereas for a subsample of children whose maximal lead concentrations remained below 10 μg, IQ declined by 7.4 points as lifetime average blood lead concentrations increased from 1 to 10 μg per deciliter.[285]

In a call for primary prevention of exposure to lead, a CDC report cautions that low level lead exposure can have a significant impact on the distribution of IQ in an entire population, by decreasing the number of children with IQs above 130 and increasing the number of children with IQs below 70.[286]

*Diminished School Performance*
Increases in blood lead levels have been consistently found to negatively impact academic performance, and blood lead has been identified as one of the contributors to the achievement gap. A study of a national sample representative of the US population of children of aged 6 to 16 years looked at the impact of blood lead concentrations below 10 μg/dL. The research found, after adjusting for potential confounders, a 0.70 point decrement in math scores and an approximate 1 point decrement in reading scores for every 1 μg/dL. The analysis showed also a 0.10 decrement in non-verbal reasoning score and a 0.05 point decline in short-term memory score for each 1 μg/dL increase in blood lead concentration. The study also found an inverse relationship for math and reading scores with blood lead concentrations lower than 5.0 μg/dL.[287]

A similar study reported a decline in math scores of -0.50 per unit increase in blood lead for 3rd grade examinations in Chicago public school children, after adjusting for relevant confounders. Furthermore, the study found that there was a 32% increased risk in both reading and math failure associated with each 5 μg/dL increase in blood lead concentration. The study also found that 13% of reading failure and 14.8% of math failure can be attributed to exposure to blood lead concentrations of 5 to 9 μg/dL vs. 0-4 μg/dL.[288]

A statewide study of North Carolina public school children found that lead exposure is associated with lower performance on reading End Of Grade (EOG) test scores in a clear dose-response pattern at all blood lead levels, with the effects increasingly more pronounced for children with the lowest academic attainment.[289] A similar study conducted in Connecticut uncovered that blood lead levels as low as 3-4 μg/dL are negatively associated with third, fourth, and fifth grade reading scores, and blood lead levels as low as 4-5 μg/dL are negatively associated with math scores.[290]

Reading scores are affected by blood lead levels as early as in kindergarten. In a study of children attending public kindergarten in Providence (RI), compared with children with blood lead levels < 5 μg/dL, there were 21% and 56% more children failing to achieve the national benchmark for reading readiness with blood lead levels of 5 to 9 and >10 μg/dL respectively. Furthermore, on average, reading readiness scores decreased by 4.5 and 10.0 points for children with blood lead levels of 5 to 9 and 10 mg/dL, respectively, compared with children of blood lead levels below 5 μg/dL.[291]

A similar study in North Carolina found that, after adjusting for potential confounders, going as low as 2 μg/dL, every 1 μg/dL increase in blood lead reduces the likelihood of children being placed in advanced and intellectually gifted programs. Also, blood lead levels as low as 4 μg/dL increase the likelihood that a child will be designated to the category for children with learning and behavioral issues. Furthermore, blood lead levels as low as 8 μg/dL significantly increase the likelihood that a child will be designated to the exceptionality category group containing students with visual, hearing, or speech impairments, physical or health handicaps, autism, or trainable or severe mental handicaps.[292]

*Speech and language deficits*
Lead exposure is also associated with speech and language deficits. A study of 11 to 14 year olds found that higher bone lead concentrations were associated with poorer performance on certain language measures. Another study on the influence of childhood lead exposure on language processing in a group of young adults found that higher childhood blood lead levels were significantly associated with reduced activity in a region of the brain known for speech production. Some studies have also found an

association between High Blood Lead Levels and small but significant deficits in hearing and central auditory processing.[293]

*Behavioral Problems*

A recent study examining the relationship between blood lead levels and ADHD among children 4-15 years of age found that blood lead concentration was a significant predictor of ADHD, and that there was a significant dose-response relationship between lead exposure and ADHD. When the sample was restricted to children with blood lead concentrations below 5 μg/dL, there was still a significant association between higher blood lead levels and ADHD.[294]

A previous study that looked at blood lead levels and behavior found significant, albeit small, relationship. The study, conducted amongst preschool children in Yugoslavia, found that blood lead explained 1% and 4% change of the variance on the Destructive and Withdrawn Subscales of the Child Behavior Checklist.[295]

Studies have also found links between increased blood lead and destructive and aggressive behaviors in children. A study of a nationally representative sample of children aged 8 to 15 years found that those with blood lead levels ≥ 1.5 μg/dL had a 8.6-fold increased odds of having symptoms of conduct disorder, compared with children with levels from 0.2 to 0.7 μg/dL. Studies have also found that lead exposure in childhood increases the likelihood of antisocial behaviors in later childhood, adolescence, and young adulthood.[296]

**Conclusions**

Key points:

- Primary prevention by addressing sources including lead based paint hazards in older, poorly maintained housing, along with screening, education of parents/caregiver and health care providers are necessary to address childhood lead exposure.
- Underserved children have significantly higher rates of high blood lead levels. At the population level, black children had significantly higher mean blood lead levels than white or Mexican American children. Mean blood lead levels were also higher in children enrolled in Medicaid and in children from poorer families. Children living in communities with older, poorly maintained housing are at greatest risk for exposure.
- These disadvantaged groups of children are therefore vulnerable to the learning consequences of lead exposure, which are decreased IQ, decreased score in academic performance tests, decreased designation as exceptionally gifted and increased designation as having learning or behavioral issues or severe handicaps. Other consequences included increased rates of ADHD and behavioral problems. Moreover, children in poverty face other factors that can increase the harmful effects of lead exposure, including exposure to other neurotoxicants (e.g. pesticides, tobacco smoke), poorer nutrition (e.g. inadequate calcium and iron intake), lack of medical coverage, increased stress, and fewer opportunities for stimulation.[297]
- Collectively, these findings clearly show the need to prevent exposure, ensure that children at risk have access to appropriate lead screening and follow up services, and provide an enriched intellectual environment and educational interventions for lead-exposed children to overcome the adverse learning effects.