Blood Lead Levels Below 10 μg/dL:

Information to Aid Decision-making and Counseling in the Health Care Setting

The Advisory Committee on Childhood Lead Poisoning Prevention

Draft version 10/02/04

ABSTRACT

In its 1991 statement, the Centers for Disease Control and Prevention (CDC) recognized that a blood lead level of 10 μg/dL did not define a threshold for the harmful effects of lead. Recent research has strengthened concerns about lead at levels <10 μg/dL, although further research is needed to bolster confidence that confounders have been adequately controlled and to delineate the strength and shape of the relationship between lead an cognitive functioning (see recent review by the Advisory Committee on Childhood Lead Poisoning Prevention, http://www.cdc.gov/web address here). We are now in that difficult position where concern for the effects of lead at low levels exists, but there are no tested medical management models on which to base therapy or management.

This document is intended to provide guidance to clinicians regarding blood lead levels <10 μg/dL. Key concepts are outlined and discussed. These areas include children's behavioral and developmental outcomes, technical information about individual blood lead measurements and their interpretation, intervention and prevention strategies, and child risk assessment and blood lead screening. As data to guide clinical actions are limited, more research is needed in these areas.

Introduction

Laboratory thresholds (i.e., values used to define abnormal results) for blood lead measurement are useful to define risk and develop action plans. However, over the past 40 years interpretations of research findings have fostered repeated lowering of thresholds associated with risk for lead. Recent research has strengthened concerns about lead at levels <10 μg/dL, although further research is needed to bolster confidence that confounders have been adequately controlled and to delineate the strength and shape of the relationship between lead an cognitive functioning (see recent review by the Advisory Committee on Childhood Lead Poisoning Prevention[1]). We are at the point where no safe level for lead can be defined. In fact, in its 1991 statement, the Centers for Disease Control and Prevention (CDC) already recognized that a blood lead level of 10 μg/dL did not define a threshold for the harmful effects of lead.[2] The nomenclature used to describe a level of 10 μg/dL, i.e., "blood lead level of concern", may have fostered a perception of *lack of concern* for blood lead values <10 μg/dL. This is not the case. The full spectrum of blood lead levels provides important information for clinicians and public health officials. A blood lead level of 10 μg/dL might more clearly be called a current "public health action level", i.e., the level communities use to assess their populations of children and to prioritize community-wide actions and implementation of lead exposure prevention strategies.

This document is intended to complement the recent review on the health effects of blood lead levels <10 μg/dL.[1] That document reviews studies that have examined the inverse association between children's blood lead levels and children's cognitive functioning among children with low blood lead levels. While recognizing that lead likely plays a role as a causal agent in the relationship, the report highlights the possibility of residual confounding and other factors which leave considerable uncertainty related to the effect size and shape of the dose-

response relationship. Additionally, there continues to be a void in our knowledge of effective management of levels this low. Further, we cannot accurately predict the effects of lead on cognitive or behavioral development for any individual child. So then, how may a clinician respond to a concerned parent whose child's blood lead level is <10 μg/dL?

This paper outlines and discusses seven key concepts to guide clinicians regarding interpretation and counseling strategies in regards to "low" blood lead levels.

This information supplements the thorough review of case management of children with blood lead levels of 10 μg/dL or higher, which clinicians should reference for guidance on that topic.[3] Particularly, that document provides a thorough review of educational and environmental strategies to lower exposures to lead; topics which are not covered in detail in this document.

1. Historical Perspective

- As recently as 25 years ago, 88% of US children aged 1-5 years had a blood lead level of 10 μg/dL or higher.
- Continuing research progress has revealed adverse health effects of lead at lower and lower blood lead levels.

Over the past 25 years, blood lead levels in US children aged 1-5 years have decreased dramatically (Table 1) primarily due to population-based policies that reduced the continued dispersal of lead into the environment.[4] During this same period, new research suggested that lead affects children's physical and mental development at considerably lower lead levels than was previously recognized.[1,] In the current era, most blood lead evaluation and management strategies are applied to clinically asymptomatic children.

Table 1: Blood Lead Levels of US Children Aged 1-5 Years

Year	Blood Lead ≥10 μg/dL, %	Blood Lead ≥5 μg/dL, %	Geometric Mean Blood Lead
1976-1980[5]	88.2%	99.8%	15.0 μg/dL
1988-1994[6]	6%	25.6%	---
1991-1994[7]	4.4%	---	2.7 μg/dL
1999-2000[8]	---	---	2.2 μg/dL

2. Children's Behavioral and Developmental Outcomes

- The specific nature and severity of neurological, behavioral, and health effects of low level lead accumulation in an individual child cannot be predicted.
- Genetic and psychosocial experiences contribute more strongly to a child's cognitive and behavioral development than does low level lead accumulation. However, lead toxicity is an important, entirely preventable cause of neurodevelopmental impairment.
- All parents should be encouraged to be aware of their child's developmental milestones and to participate in nurturing activities in order to assist their child in reaching his or her full developmental potential.
- Clinicians should appropriately screen children for developmental problems and seek further evaluation and therapy, as necessary.

Although it is an important, unnecessary danger, lead is not the primary factor affecting a child's risk for neurological sequelae. In studies of low-level lead exposure, the variance in neurodevelopmental measures accounted for by the child's blood lead measurement is generally

estimated to be around 2 to 4%.[,9] Parental intelligence and socioeconomic status account for a far greater proportion of the variance in the neurodevelopmental measures than does lead, at least at the lead levels experienced by the children who participated in these studies.[,10]

An elevated blood lead measurement is a risk factor for developmental and behavioral problems, but is not diagnostic of such. There is no characteristic developmental pattern to the effects of lead. Recent documents review studies that have examined the myriad effects of lead on a child's development outcomes.[1,]

Studies vary widely on the particular blood lead measurement or calculation most strongly associated with neurocognitive outcomes. Many studies have found strongest relationships by using a calculation of average blood lead over a specific time period,[11, 12, 13, 14] for example at 0-5 years. Other studies found significant associations with single measurements,[15, 16, 17]for example at specific ages (e.g., 24 months) or at a peak measurement. Concurrent blood lead levels in school-aged children have been significantly negatively associated with neurodevelopmental abilities.[18, 19]

Children's brains undergo rapid development in early childhood. Parents have the opportunity to positively influence child development by providing nurturing experiences in their home environment. All children can benefit from this, regardless of their blood lead level. Developmental and behavioral assessment and specific, objective developmental testing, as necessary, is a cornerstone of routine clinical care.[20] Children with developmental delay achieve greater benefit from interventions applied at an early age.[21] Clinicians should appropriately screen all children regardless of their blood lead level for developmental achievement, and seek further evaluation and therapy for the child, as necessary. Early enrichment programs have not been evaluated in relationship to blood lead levels, but have been effective in improving

cognitive development and social competence of young children, particularly for infants from families with low levels of economic and social resources.

3. Blood Lead Measurements

- Blood lead measurements always include some inherent uncertainty due to the imprecision related to the analytic technique used, and to pre-analytic variables such as those associated with the specimen collection process. The uncertainty includes both random and systematic error.
- Current federal regulatory requirements permit laboratories to operate with a fixed allowable error of ±4 μg/dL for blood lead, i.e., a range of 8 μg/dL, at these low levels. However, most laboratories can achieve routine performance of achieve routine performance of ±2 μg/dL.
- A blood lead result should be interpreted within the context of the particular laboratory, and the specific analytical methodology used to produce the test result.

While uncertainty in blood lead measurements is not unique to blood lead levels below 10 μg/dL, the relatively high ratio of laboratory uncertainty to measurement value makes a clear understanding of this concept very important at these lower levels.

Laboratory

Among the various analytic methodologies used for blood lead measurements, graphite furnace atomic absorption spectrometry is currently the most widely used.[22, 23, 24] However, the performance of any laboratory, regardless of the methodology used, is highly dependent on the skills of the laboratory team.[25]

All clinical laboratories in the US must be certified under the Clinical Laboratory Improvement Amendments of 1988, and those that offer blood lead testing must participate

satisfactorily in an approved proficiency testing program. However, under current federal regulations, laboratories performing blood lead testing are permitted to operate with a total allowable error of ±4 μg/dL or ±10%, whichever is greater. This means that at blood lead levels 10 μg/dL and below, a laboratory can operate within an error range of 8 μg/dL and still be considered proficient. For example, a "true" value of blood lead at 7 μg/dL could be reported anywhere in the range of values of 3 μg/dL to 11 μg/dL. A study of duplicate testing of blood samples (all samples with a mean blood lead value <10 μg/dL) at 8 laboratories reported all results as <10 μg/dL and within 3 μg/dL of the overall mean for that specimen value.[27] Today, however, most blood lead laboratories can easily achieve routine performance of ±2 μg/dL.[28]

Collection Methods

Blood collection by venipuncture is considered to be the blood collection method least subject to environmental contamination. This collection method has been used as the standard against which other collection methods are evaluated, but may be difficult to achieve in some settings.

Collection of capillary blood from a fingerstick into a lead-free collection device works well as a screening test.[31, 32, 33, 34, 35] As the finger surface can become contaminated by lead, a protocol for proper capillary specimen collection should be utilized to minimize this.[36] However, since lead levels obtained by fingerstick collection methods will vary somewhat from those of a simultaneously drawn venous sample, confirmation of results is needed for elevated samples. While there is some data to estimate the uncertainty introduced by collecting blood from a fingerstick versus a vein at thresholds of 10 or 15 μg/dL,[,,,,] there are no studies that have examined sensitivity or specificity of fingerstick testing methods at thresholds less than 10 μg/dL.

4. Patterns to Children's Blood Lead Levels

- Changes in blood lead measurements over time reflect both acute and chronic accrual of lead.
- Characteristic age- and season-related blood lead level patterns are evident for blood lead levels in high-risk cohorts. Age-related patterns may not be as clearly evident in cohorts with blood lead levels <10 μg/dL.

Distribution of Lead in the Body

Lead is unevenly distributed within the human body; in children approximately 70 percent is stored in the bone compartment.[37, 38, 39] The blood lead level rises quickly after an acute exposure, then gradually (over weeks) reaches equilibrium with body stores of lead. Lead in bone, which is measured in research studies using X-ray fluorescence, is the best assessment of body stores of lead, as the residence time of lead in bone can be decades.[40] A blood lead measurement may be high and decline fairly rapidly following an acute exposure if the exposure is stopped and the child's prior accrual of lead was low. If the child's blood lead is already in equilibrium with the bone lead stores, the measured blood lead level is more likely to persist at a subsequent measurement.[41]

Once a pattern of a higher blood lead has been established in children, the time required to drop back to the baseline lower level is months to years, depending on the duration of exposure. For example, the time for 50% of children with a blood lead of 10-14 μg/dL who are receiving case management services to fall to a blood lead <10 μg/dL was 9 months. Similarly, the period for children with a blood lead of 15-19 μg/dL to fall to <10 μg/dL was 14 months.[42] The time for blood lead levels <10 μg/dL to fall to even lower levels has not been reported.

Age

The blood lead level of a newborn infant closely reflects the blood lead level of the mother.[43] The geometric mean blood lead level for US women age 20 or older is 1.4 μg/dL. In 1988 to 1991, an estimated 0.5% of women of child-bearing age had a blood lead level ≥10 μg/dL.[44]

Mirroring a child's developmental stages, several longitudinal studies report an expected rise in blood lead during late infancy with a peak blood lead level found between 18 and 36 months of age.[15, 46, 47, 48] However, this pattern of peak blood lead near age 2 years was not as evident in low-risk cohorts in which blood lead levels remained <10 μg/dL for most children throughout the study period.[49] In such low-risk cohorts, blood lead fluctuation was not as strongly associated with the child's age.

Season

The pattern of seasonal variability of blood lead measurements is a well-established phenomenon.[50, 51] In Boston, blood lead levels were highest in late June and lowest in March. In Milwaukee, blood lead levels were about 40% higher in summer than in winter. An analysis of seasonal changes in residential dust lead content in relationship to children's blood lead concluded that some of the variability (higher blood lead in summer) is due to increased exposure to lead in dust and soil.[52] Investigators found that during the summer months there were higher levels of lead in the dust in the homes and an increased duration of outdoor play.[52]

5. Intervention and Prevention Strategies

- Every child should live in a lead-safe home regardless of his or her blood lead level.
- There are no studies that have examined the effectiveness of education delivered in the primary care office setting on the prevention of blood lead elevation.
- Preventive interventions delivered in the home and focused on parental education and

provision of supplies to increase home cleaning have shown absent or modest effects on average blood lead levels, but may reduce the likelihood of further increases.

- Educational counseling at these lower blood lead levels should focus on enabling parents to recognize potential sources and pathways for lead exposure and application of environmental and behavioral steps that may help to reduce exposure to known or suspected sources of lead.
- Although medical management guidelines have been issued for children with blood lead levels ≥10 μg/dL, their application to blood lead levels <10 μg/dL has not been evaluated.

The major source of lead exposure for US children is lead-contaminated house dust.[53] Residence in a lead-safe home decreases the likelihood of a child's exposure to lead-based paint hazards. While every child should live in a lead-safe home, this is not the current reality. Twenty-five percent of US homes with children—an estimated 4.1 million homes—have a lead-based paint hazard.[54] Sufficient public funds are not currently available to promptly and comprehensively address this extensive problem. In fact, publicly-funded home inspections are generally limited to homes of children with elevated blood lead levels and the blood lead threshold value that triggers an inspection varies by state or municipality.[55] Additionally, public funding for lead hazard repair is usually not available even when a child's blood lead elevation has triggered a home inspection. To protect children's health before the child's blood lead level is at or above 10 μg/dL, property owners should foster preventive actions in the housing units they own by identifying lead-based paint hazards and using lead-safe work practices to reduce hazards.[56,57] Findings of the US Department of Housing and Urban Development's Lead-Based Paint Hazard Control Grant Program indicate that if occupant protection practices (e.g.,

clearance testing, workplace containment requirements, and relocation of families if the work warrants) are followed, homes may undergo lead hazard reduction activities to achieve substantial reductions in lead dust levels[58] and children's blood lead levels will not significantly increase.[59] However, one should only promote renovations/repairs that are done by individuals expertly trained in safe repair of lead-containing surfaces and who apply occupant protection practices during repairs and until the work areas have passed clearance tests verifying that very low residual levels of lead remain. If proper precautions are not followed, the child's exposure to lead will be increased instead of decreased.[60]

The CDC, through its state and local health department lead grantees, and its federal partners, particularly the U.S. Department of Housing and Urban Development and the U.S. Environmental Protection Agency, are working to promote wide-spread primary prevention strategies to pro-actively reduce hazardous exposures to lead.[61] Clinicians and parents should be encouraged to contact state and local health departments to learn more about local opportunities. Clinicians can advocate for primary prevention activities in their communities.

In the 1991 statement, the lack of tested, effective interventions for children with blood lead levels <15 μg/dL was recognized. This is still true today. Several prospective studies have applied educational strategies among primarily low-income, high-risk populations using study designs that included control groups. Lanphear et al found no effect of provision of repeated educational sessions (up to 8) in the home and provision of cleaning supplies starting in infancy on the prevention of blood lead elevation through 24 months [63] and 48 months.[64] Jordan et al reported that among families receiving an intensive peer education program beginning at the birth of the child (28 sessions over 3 years), the risk of a blood lead ≥10 μg/dL was reduced by 34%.[65] A systematic review of four studies, [66] two involving education[64, 67] and two involving

professional cleaning,[68], [69] found that overall such low-cost interventions reduced the proportion of children with blood lead levels ≥15 μg/dL and ≥20 μg/dL, but had no meaningful effect on the mean blood lead level. Individually, the study by Rhoads et al[68] reported a 17% decrease in the mean blood lead level following a one-year period of professional cleaning. This strategy can be used without subjecting children to a risk of increased lead exposure from unsafe repair methods (i.e., methods not in compliance with lead-safe work practices) of lead-containing or lead-contaminated surfaces. Several publications,[70] comprehensively review studies that have examined the effects of various strategies to prevent blood lead elevation or more rapidly reduce blood lead elevation. However, no studies have specifically evaluated the effectiveness of strategies that apply risk assessment and educational processes in the medical office setting on the prevention of blood lead elevation.

The CDC, and the American Academy of Pediatrics[71] have published recommendations for evaluations and educational topics to be covered in lead poisoning prevention and intervention efforts. These are based on the current understanding of lead exposure pathways and risks and potential sources of lead. The recommendations include environmental evaluation and containment of sources of lead exposure and recommend actions parents can undertake in their home environment that might reduce a child's exposure to sources of lead. These recommendations should be used to guide educational efforts for children with blood lead levels <10 μg/dL. Although medical management guidelines have been issued for children with blood lead levels ≥10 μg/dL, medical management strategies for children with blood lead levels <10 μg/dL have not been developed or evaluated.

6. Blood Lead Screening

- Clinicians should comply with blood lead risk assessment and blood lead screening

recommendations issued by their state or local health department.

Recommendations for blood lead screening have not changed. Current CDC[72], and AAP[71] guidelines recommend a blood lead test on all children enrolled in Medicaid and those identified at risk according to the state or local screening plan or by the risk assessment process. Current federal policy requires all children enrolled in Medicaid to receive screening blood lead tests at 12 and 24 months, and further that blood lead screening be performed for children ages 36-72 months who have not previously been screened.[73]

In 1997, the CDC called upon state and local health officials to develop regional or local strategies for blood lead screening based on local population-wide data (e.g., blood lead level prevalence, housing age, poverty status).[73] State or local health departments guided the development of their specific screening plans through a process designed to include all stakeholders. Plans were then issued by the health departments to clinicians in their jurisdiction. Plans may recommend either universal or targeted lead screening. Targeted-screening strategies uniformly apply personal-risk assessment tools to determine risks for exposure to lead and recommend blood lead testing for a subset of the jurisdiction's children thought to be at increased risk for lead exposure. The CDC recommended that risk evaluations be based on factors such as residence in a geographic area, membership in a high-risk group, answers to a personal-risk assessment questionnaire (which may include local factors such as cultural practices or products), or other relevant jurisdictional risk factors.[72]

CDC recommends that the locally-developed targeted risk assessment and blood lead screening strategies be applied at ages 1 and 2 years, and that children aged 36-72 months who meet risk assessment criteria and who have not previously been screened also be receive a blood lead test.[72] For those clinicians in areas that lack a state or local screening plan, the CDC

recommends that a blood lead test be performed on all children at age 1 and 2 years and on children aged 36-72 months who have not previously been screened.[72]

The AAP guidelines recommend a first evaluation at ~9 to 12 months and a second at 2 years.[71] Screening at approximately ages 1 and 2 years is recommended because lead exposures may change with a child's developmental progress or change due to external factors (e.g., family relocation, home remodeling). Among high-risk children in Chicago with a blood lead level <10 μg/dL at age 1 year, 21% had a blood lead ≥10 μg/dL when tested again at age 2 or older.[73] The effects of variations in risk assessment or screening strategies (e.g., variations in age or frequency of risk assessment or blood lead testing) on outcomes, such as peak or average lifetime blood lead levels, have not been reported.

7. Risk Assessment Questionnaires

- There are no studies that have examined the predictive value of risk assessment questions for blood lead levels at cut-points lower than 10 μg/dL.

The effectiveness of a diligent application of a personal-risk assessment process for use in identifying children who may benefit from blood lead screening will vary by population. Personal risk-assessment methods vary in their sensitivity and specificity. Even at a cut point of 10 μg/dL, only some of the children with elevated blood lead levels would receive a blood lead test based on application of a risk questionnaire.[74, 75, 76] Nearly all studies that have evaluated personal-risk assessment questionnaires have found sensitivity and specificity to be lower at a cut-off of 10 μg/dL than for higher cut-off levels. No studies have evaluated the performance of personal-risk assessment questionnaires at cut-off levels lower than 10 μg/dL.

Research Needs

Further study on the effects of lead at levels <10 μg/dL is needed to improve the

understanding of the effects of low levels of lead on child functioning and to guide development of management guidelines for children with blood lead levels <10 μg/dL. This will involve following large, diverse populations with careful attention to potential confounders, with particular attention to application of state-of-the-art measurements of social factors. Research is also needed to evaluate the effectiveness of office-based anticipatory guidance for lead poisoning prevention, as well as the effectiveness of medical and environmental management strategies for children with blood lead levels <10 μg/dL. Evaluations of blood lead screening strategies should examine best ages for screening and the utility of the targeted screening at the community level and of risk assessment methods at the individual level for children with blood lead levels <10 μg/dL. This will include determining the predictive value of risk assessment questionnaires for blood lead level cut-points lower than 10 μg/dL. A means to evaluate individual laboratories and provide this information to clinicians should be developed. Perhaps laboratories should participate in blinded evaluations of their performance and be required to report confidence intervals for test results based on such evaluations.

Conclusions

Data to guide clinical actions related to blood lead levels <10 μg/dL are limited and there is a need for more research in these areas and for improvements in laboratory methods and laboratory performance monitoring. However, there *is* sound evidence that lead hazards in the home (e.g., lead-contaminated dust, deteriorating lead-containing paint) are primary sources for child exposure to lead and that lead abatement—when applied in compliance with state and federal regulations using skilled workers and lead-safe work conditions—successfully and safely reduces lead hazards. Clinicians should raise awareness about lead hazards in the home and about the need to safely implement control measures before blood lead levels rise. It is

counterproductive to withhold this information until children's blood lead levels are elevated. Clinicians should be aware of lead screening strategies and apply them as directed by their state or local health department. Clinicians should partner with public health agencies and parents to work toward ensuring lead-safe living conditions for all children and toward the reduction of exposure to lead from other sources.

ACKNOWLEDGEMENT

With appreciation to Patrick J. Parsons, Ph.D, C.Chem., FRSC., Director, Lead Poisoning/Trace Elements Laboratory, New York State Dept. of Health, Albany, NY, and Associate Professor, Department of Environmental Health and Toxicology, School of Public Health, The University at Albany, State University of New York, Albany, NY, and David C. Bellinger, Ph.D., M.Sc., Professor of Neurology, Harvard Medical School and Professor of Environmental Health, Harvard School of Public Health, Boston, MA, for their helpful suggestions and reviews of this document.

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[36] Recommended to insert a reference to CDC written protocol, CDC video instructions. These are not on the CDC web site nor can I find where these are published or publicly available. Someone needs to find this, else use citation below.

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