The findings of a wide variety of international studies on the impacts of lead exposure on mental development persuaded many countries to progressively reduce the amount of lead exposure deemed safe during childhood. Since 1991, the U.S. Centers for Disease Control and Prevention (CDC) has recommended 10 µg/dL (0.48 µmol/L) as the pediatric blood lead level deemed safe during childhood. Since then, maternal lead exposure during the course of pregnancy (Mendola et al. 2002). Thus, it is plausible that lead exposure may be particularly neurotoxic during a specific trimester.

Recent evidence also suggests that whole blood lead levels in a pregnant woman might not be the optimal marker for lead concentrations in the fetal brain. Over 99% of lead in whole blood is bound to red cells and thus not

BACKGROUND: The impact of prenatal lead exposure on neurodevelopment remains unclear in terms of consistency, the trimester of greatest vulnerability, and the best method for estimating fetal lead exposure.

OBJECTIVE: We studied prenatal lead exposure's impact on neurodevelopment using repeated measures of fetal dose as reflected by maternal whole blood and plasma lead levels.

METHODS: We measured lead in maternal plasma and whole blood during each trimester in 146 pregnant women in Mexico City. We then measured umbilical cord blood lead at delivery and, when offspring were 12 and 24 months of age, measured blood lead and administered the Bayley Scales of Infant Development. We used multivariate regression, adjusting for covariates and 24-month blood lead, to compare the impacts of our pregnancy measures of fetal lead dose.

RESULTS: Maternal lead levels were moderately high with a first-trimester blood lead mean (± SD) value of 7.1 ± 5.1 µg/dL and 14% of values ≥ 10 µg/dL. Both maternal plasma and whole blood lead during the first trimester (but not in the second or third trimester) were significant predictors (p < 0.05) of poorer Mental Development Index (MDI) scores. In models combining all three trimester measures and using standardized coefficients, the effect of first-trimester maternal plasma lead was somewhat greater than the effect of first-trimester maternal whole blood lead and substantially greater than the effects of second- or third-trimester plasma lead, and values averaged over all three trimesters. A 1-SD change in first-trimester plasma lead was associated with a reduction in MDI score of 3.5 points. Postnatal blood lead levels in the offspring were less strongly correlated with MDI scores.

CONCLUSIONS: Fetal lead exposure has an adverse effect on neurodevelopment, with an effect that may be most pronounced during the first trimester and best captured by measuring lead in either maternal plasma or whole blood.

available to cross the placenta (Goyer 1990); instead, it is the < 1% of lead in the plasma compartment of blood that is of greatest interest in terms of fetal exposure. Recent data suggest that there are significant interindividual differences in the ratio of red cell lead to plasma lead (Hu 1998; Lamas´-Figueroa et al. 2006), making maternal whole blood lead levels potentially unreliable as a proxy for plasma lead and fetal exposure (Chuang et al. 2001; Goyer 1990).

To date, no study of fetal lead neurotoxicity has included the biomarker measurements needed to compare whole blood and plasma lead levels during each trimester of pregnancy as predictors of infant neurodevelopment. It is such a comparison that we report here.

Materials and Methods

Study subjects. Subjects were recruited between May 1997 and July 1999 from 2,273 women approached during prenatal visits at one of three clinics of the Mexican Institute of Social Security (IMSS) in Mexico City. Women were eligible if they had a confirmed positive β-human chorionic gonadotropin test or were trying to become pregnant, lived in Mexico City, and were willing to participate in the 3-year follow-up study protocol. Of the 2,273 women approached, 1,502 (66%) declined to be enrolled. We applied the following exclusion criteria to the 771 (34%) women who became pregnant, agreed to participate, and became pregnant in the near future and declared an intention to become pregnant within the following 5 years (3.7%); having a psychiatric disorder (0.3%); and being pregnant with >14 weeks of gestation (0.7%); suffering from gestational diabetes (0.7%); diagnosis of high-risk pregnancy (0.0%); continuous use of prescription drugs (0.0%); diagnosis of hypertension (8.4%), or gestational diabetes (0.7%); suffering from seizures that required medical treatment (0.0%); and being pregnant with >14 weeks of gestation (15.3%). A total of 280 already pregnant women were recruited; 182 women with a negative pregnancy test declared an intention to become pregnant in the near future and were also recruited. Of the latter group, 47 became pregnant, agreed to participate, and were enrolled in the cohort comprising a total of 327 pregnant women.

Of these 327 women, 216 continued the full follow-up and bore children who were evaluated for the Bayley Mental Development Index (MDI) (Bayley 1993) at 24 months of age. Of these 216 mother–infant pairs, 146 met the following inclusion criteria: child born with at least 37 weeks of gestational age; at least one valid measurement of plasma lead during any of the three visits made during pregnancy; complete information on maternal age; IQ; and child’s blood lead level at 24 months of age, sex, weight, and height.

All mothers were informed about the study; those who agreed to participate read and signed a letter of informed consent. The research protocol was approved by the Ethics Committees of the National Institute of Public Health of Mexico, the Harvard School of Public Health, the Brigham and Women’s Hospital, the University of California, and the participating hospitals.

Blood and plasma lead measurement in mothers. Blood and plasma samples were collected during each prenatal visit of the mothers to the Center for Environmental Health Research of the American British Cowdray (ABC) Hospital in Mexico City. Visits were scheduled at 12, 24, and 34 weeks of pregnancy, and samples were classified as corresponding to first, second, or third trimester according to the timing of these visits. Subjects were instructed to fast overnight before sample collection. Before venipuncture, each subject’s arm was washed with ultrapure water and disinfectant with reagent-grade alcohol. Three milliliters of venous whole blood was collected with a butterfly catheter (19 gauge) into a low-lead container (Vacutainer B-D 367734; Becton-Dickinson, Franklin Lakes, NJ, USA) for blood lead analysis, and 13 cm² venous blood was then collected into a polyethylene tube containing 100 ISP (international units) sodium heparin (H-3393; Sigma Chemical Company, St. Louis, MO, USA), processed, and shipped to the trace metal facility at the University of California, Santa Cruz, for measurement of whole blood lead and plasma lead using ultra-clean methods detailed elsewhere (Hernandez-Avilà et al. 1998; Smith et al. 1998). All samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS; Thermo Finnigan, Bremen, Germany). Potential contamination by lead from hemo-lyzed red cells was assessed by measuring levels of plasma iron and free hemoglobin using sensitive methods previously described in detail (Smith et al. 1998). Accordingly, 18 samples were determined to be contaminated and excluded from further analyses.

Children’s blood lead measurement. Umbilical cord and infant venous blood samples at 24 months were collected in trace metal–free tubes. Due to the logistical constraints posed by the collection of samples during birth from multiple hospitals and at unpredictable hours, we obtained data on cord blood on only 57% of the mothers participating in this study. Samples were analyzed for lead using an atomic absorption spectrometry (AAS) instrument (model 3000; PerkinElmer, Chelmsford, MA, USA) at the metals laboratory of the ABC Hospital, which participates in the external validation protocol of the Wisconsin Laboratory of Hygiene. The Pearson correlation coefficient between all available measurements by AAS and those by ICP-MS was 0.93 (in mothers). Precision was similar using either measuring technique; standard deviations were not significantly different (p = 0.32); and accuracy was comparable (with difference in means < 1.0 µg/dl).

Measurement of child development and potential confounders. Infant development at 24 months was assessed by trained personnel using the Bayley Scales of Infant Development II–Spanish version (BSID-II) (Bayley 1993) using a standardized protocol described in a previous study by our research group (Gomaa et al. 2002). All assessors were blind to the children’s in utero and postnatal lead measurements. MDI scores at 24 months of age were considered the primary outcome. Information on demographic, socioeconomic, and other factors that could confound the relationship between lead and child development was collected. Maternal IQ was assessed using the Information, Comprehension, Similarities, and Block Design subtests of the Wechsler Adult Intelligence Score (Wechsler 1968).

Statistical analysis. Descriptive statistics and appropriate transformations were performed before bivariate analyses. Outliers were identified using the ESD (Extreme Studentized Deviate) Many-Outlier procedure (Rosner 1983). We calculated Spearman correlation coefficients among the lead measurements. Height and weight data were transformed into Z-scores by using World Health Organization (WHO)/National Center for Health Statistics/CDC reference data (WHO 1979) and interpreted as indices of a child’s nutritional status. Variables considered to be potential confounders based on biologic plausibility, regardless of statistical significance, and those significantly (p < 0.1) associated with MDI scores in bivariate analyses were included in multiple linear regression models; given these criteria, confounders included were child’s sex, blood lead at 24 months of age, height for age z-score and weight, as well as maternal age and intelligence quotient. All models featured log-transformed lead measures because this procedure provided the best fit. We first generated “single-trimester” models, in which we evaluated the associations between MDI score and log-transformed plasma and whole blood lead levels during each trimester of pregnancy adjusting for potential confounders. We generated “multi-trimester” models, incorporating in each model, the data from either plasma or whole blood lead concentrations from all three trimesters. We also ran models using maternal plasma lead or whole blood lead, averaged over all three trimesters. Infant lead levels were log-transformed to enable better comparability of the relative effects of plasma lead and blood lead, we compared effect estimates for a 1-SD change in each exposure metric. We carried out a similar analysis using log-transformed cord blood lead levels as a proxy variable for prenatal lead.
Each line in the table represents a different model. Logarithmically transformed lead concentrations were used. CI, confidence interval. Each model is adjusted for infant’s concurrent blood lead (24 months of age), sex, maternal age, birth weight, height, and MDI when compared with mother–child pairs who participated but who did not meet the inclusion criteria for this analysis (n = 70; data not shown). Circulating levels of lead in the included mothers were moderately high, with mean (± SD) values for first-trimester whole blood lead of 70.7 ± 51.0 µg/L and 14% of values > 10 µg/L (Table 1). (Whole blood lead values are expressed in this article as micrograms per liter for ease of comparison with plasma levels.) Both maternal plasma and whole blood lead followed a U-shaped pattern over the course of pregnancy, reaching their lowest points during the second trimester and rising during the third trimester.

As expected, relationships of lead bio-markers in the three stages of pregnancy were moderately well correlated (all p < 0.05); Spearman correlations between blood lead measurements at different stages of pregnancy (mean = 0.72; range, 0.67–0.81) were, on average, higher than their plasma lead counterparts (mean = 0.62; range, 0.55–0.69). Cord blood lead was most highly correlated with maternal whole blood lead measured during the third trimester of pregnancy (r = 0.54, p < 0.001). Cord blood lead concentrations were 10.6 µg/L lower, on average, than maternal whole blood lead levels at delivery. Children’s whole blood lead levels at 12 and 24 months of age were correlated (r = 0.58, p < 0.01) and lower, on average, than their cord blood lead levels.

### Results

In the 146 mother–infant pairs in our final study group, no differences significantly greater than zero were noted in maternal age, number of years in school, IQ, and children’s hemoglobin, height, weight, and MDI when compared with mother–child pairs who participated but who did not meet the inclusion criteria for this analysis (n = 70; data not shown). Circulating levels of lead in the included mothers were moderately high, with mean (± SD) values for first-trimester whole blood lead of 70.7 ± 51.0 µg/L and 14% of values ≥ 10 µg/L (Table 1). (Whole blood lead values are expressed in this article as micrograms per liter for ease of comparison with plasma levels.) Both maternal plasma and whole blood lead followed a U-shaped pattern over the course of pregnancy, reaching their lowest points during the second trimester and rising during the third trimester.

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### Table 1. Characteristics of the study population of mother–infant pairs.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>No.</th>
<th>Mean ± SD</th>
<th>Range</th>
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<tbody>
<tr>
<td>Mothers</td>
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<tr>
<td>Age (years)</td>
<td>146</td>
<td>27.1 ± 5.3</td>
<td>15–43</td>
</tr>
<tr>
<td>IQ</td>
<td>146</td>
<td>89.1 ± 12.9</td>
<td>55–120</td>
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<tr>
<td>Whole blood lead (µg/L)</td>
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<td></td>
<td></td>
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<tr>
<td>First trimester</td>
<td>119</td>
<td>70.7 ± 51.0</td>
<td>14.9–435.9</td>
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<tr>
<td>Second trimester</td>
<td>136</td>
<td>60.8 ± 31.5</td>
<td>15.8–224.4</td>
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<tr>
<td>Third trimester</td>
<td>132</td>
<td>68.6 ± 42.3</td>
<td>15.3–330.8</td>
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<tr>
<td>Delivery</td>
<td>111</td>
<td>72.6 ± 43.3</td>
<td>15–324</td>
</tr>
<tr>
<td>Plasma lead (µg/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First trimester</td>
<td>119</td>
<td>0.16 ± 0.14</td>
<td>0.04–0.99</td>
</tr>
<tr>
<td>Second trimester</td>
<td>136</td>
<td>0.14 ± 0.11</td>
<td>0.03–0.67</td>
</tr>
<tr>
<td>Third trimester</td>
<td>132</td>
<td>0.16 ± 0.24</td>
<td>0.03–2.63</td>
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<tr>
<td>Children</td>
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<td>Birth weight (g)</td>
<td>146</td>
<td>3,144 ± 359</td>
<td>2,125–4,000</td>
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<tr>
<td>Male sex (%)</td>
<td>76</td>
<td>52.05</td>
<td></td>
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<tr>
<td>Blood lead (µg/L)</td>
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<td></td>
<td></td>
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<tr>
<td>Cord</td>
<td>83</td>
<td>62.0 ± 38.8</td>
<td>9–200</td>
</tr>
<tr>
<td>12 months</td>
<td>125</td>
<td>52.2 ± 34.1</td>
<td>9–204</td>
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<tr>
<td>24 months</td>
<td>146</td>
<td>47.9 ± 37.1</td>
<td>8–368</td>
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<tr>
<td>Height at 24 months (cm)</td>
<td>146</td>
<td>86.1 ± 3.0</td>
<td>74–93</td>
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<tr>
<td>Weight at 24 months (kg)</td>
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<td>11.98 ± 3.0</td>
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<tr>
<td>Hemoglobin (g/dL)</td>
<td>135</td>
<td>12.4 ± 1.2</td>
<td>7.1–14.8</td>
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<tr>
<td>MDI score at 24 months</td>
<td>146</td>
<td>47.9 ± 37.1</td>
<td>8–368</td>
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</table>

<table>
<thead>
<tr>
<th>Variable</th>
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<th>p-Value</th>
<th>95% CI</th>
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<tr>
<td>Pregnancy</td>
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<tr>
<td>Blood lead (µg/L)</td>
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<td></td>
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<tr>
<td>First trimester</td>
<td>119</td>
<td>−4.13</td>
<td>0.04</td>
<td>−8.10 to −0.17</td>
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<tr>
<td>Second trimester</td>
<td>136</td>
<td>−4.08</td>
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<td>−8.29 to −0.12</td>
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<td>132</td>
<td>−2.42</td>
<td>0.23</td>
<td>−6.38 to 1.54</td>
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<tr>
<td>Average*</td>
<td>146</td>
<td>−3.52</td>
<td>0.10</td>
<td>−7.66 to 0.63</td>
</tr>
<tr>
<td>Plasma lead (µg/L)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First trimester</td>
<td>119</td>
<td>−3.77</td>
<td>0.03</td>
<td>−7.12 to −0.42</td>
</tr>
<tr>
<td>Second trimester</td>
<td>136</td>
<td>−2.48</td>
<td>0.13</td>
<td>−5.74 to 0.77</td>
</tr>
<tr>
<td>Third trimester</td>
<td>132</td>
<td>−0.32</td>
<td>0.83</td>
<td>−3.38 to 2.74</td>
</tr>
<tr>
<td>Average*</td>
<td>146</td>
<td>−3.11</td>
<td>0.07</td>
<td>−6.53 to 0.31</td>
</tr>
<tr>
<td>Delivery</td>
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<tr>
<td>Cord blood lead (µg/L)</td>
<td>83</td>
<td>−0.35</td>
<td>0.88</td>
<td>−4.72 to 4.03</td>
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<tr>
<td>Postnatal</td>
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<tr>
<td>Child blood lead (µg/L)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>125</td>
<td>−2.38</td>
<td>0.23</td>
<td>−6.24 to 1.49</td>
</tr>
<tr>
<td>24 months</td>
<td>146</td>
<td>−1.00</td>
<td>0.50</td>
<td>−3.93 to 1.94</td>
</tr>
</tbody>
</table>

*The arithmetic mean of log-blood lead or log-plasma lead using all available measurements.
Single-trimester models of MDI scores (Table 2) suggested a negative relationship between circulating lead in each trimester of pregnancy and MDI scores at 24 months of age, adjusting for maternal age and IQ and child’s concurrent blood lead, sex, weight and height-for-age Z-score. MDI was most strongly associated with lead concentrations during the first trimester for both plasma (standardized coefficient, –4.13; p = 0.03) and whole blood lead (standardized coefficient, –3.77; p = 0.04). Both maternal plasma and whole blood lead averaged over all three trimesters had associations with MDI of borderline significance (standardized coefficients of –3.52, p = 0.07; and –3.11, p = –0.10, respectively).

When we repeated the analysis using only those measurements correctly classified in each trimester of pregnancy, we found that lead concentrations during the first trimester were significantly associated with a decrease in MDI at 24 months of age. The estimated coefficients in the first trimester (n = 56) were –6.39 (p = 0.04) and –6.94 (p = 0.04) points per log micrograms per liter of plasma and whole blood lead, respectively. The coefficients for the second trimester plasma and whole blood lead levels (n = 102) were much smaller (–1.73, p = 0.38; and –3.66, p = 0.16, respectively). Umbilical cord lead at birth and infant whole blood lead at 12 and 24 months were inversely but weakly (p > 0.20) associated with MDI at 24 months.

In multitrimester models (Table 3), the plasma lead model predicts that an increase of 1 SD in loge-transformed plasma lead in the first trimester is associated with a 15-point decline in MDI score at 24 months of age, in contrast to a 4-point decline per 0.1–µg/L increase in plasma lead for observations above the median plasma lead—confirming that the nonlinear pattern is not an artifact of our transformation of the variable.

**Discussion**

This study is the first of which we are aware that attempted to compare the relative influence on neurodevelopmental toxicity of two different biomarkers of fetal lead exposure at each stage of pregnancy. We found that both maternal blood lead and maternal plasma lead vary considerably over pregnancy; first-trimester levels of either measures were better than second- or third-trimester levels or levels averaged over all three trimesters at predicting infant neurobehavioral performance at age 24 months; and first-trimester maternal plasma lead levels were somewhat better than first-trimester maternal whole blood lead levels at predicting infant neurobehavioral performance at 24 months of age.

Our study had several limitations. Our sample size was modest, a reflection of the labor- and cost-intensive nature of collecting plasma samples using a rigorous protocol. Nevertheless, we were able to successfully distinguish and compare the relative contributions to neurodevelopment of trimester- and biomarker-specific measures of exposure. Our subjects were a small subset of women who had been initially approached in the clinics (n = 2,273), raising the issue of the generalizability of our study. However, the women included in our final sample did not differ significantly from other eligible subjects on key covariates, suggesting that our sample was quite representative of the study population.

![Figure 2. Plasma lead levels in the first trimester of pregnancy versus MDI scores at 24 months of age. CI, confidence interval. Curve indicates the best-fit model for the association between plasma lead levels and MDI scores, adjusting for plasma lead levels in the second and third trimesters, mother’s age and IQ, child’s blood lead levels at 24 months of age, sex and height-for-age Z-score. Vertical line marks average plasma lead concentration when whole blood lead equals 100 µg/L.](image-url)
representative of the women serviced by our participating clinics. Some of our observations were misclassified with respect to trimester; however, our results were very similar in the reanalysis using classification corrections. Indeed, the association between first-trimester lead exposure and infant neurodevelopment appeared to be even greater, a finding that sug-
gests that there was downward bias due to
improper assignment of second-trimester
women to the first trimester category. We did
not control for a summary measure of home
conditions, such as the Home Observation for
Measurement of the Environment (HOME) score; however, the absence of this covariate is
unlikely to explain differences in effects
among the three trimesters of lead exposure.
Finally, offspring blood lead levels at 24 months
did not significantly predict lower MDI score; on the other hand, our sample
size, again, was modest, and in a separate
analysis of the larger group of mother–infant
pairs participating in this research (n = 294)
that was not confined to women who had
retained bone lead burdens from earlier lead
exposures. The women in our study fell into
the latter category, having lived in Mexico
City, where leaded gasoline was combusted
until 1997. Some have suggested that fetal lead
exposure resulting from the mobilization of
maternal bone lead stores during pregnancy
can be reduced by calcium supplementation
(Gulson et al. 2004; Janalikaraman et al. 2003).
Our study suggests that if such a strategy were
to prove useful in reducing lead exposure to
the fetus, it would have to be implemented
very early in pregnancy to maximize the benefit
to fetal neurodevelopment.

Our findings do not mean that measure-
ment of maternal plasma lead is likely to
become a clinically useful environmental
health tool. The methods required to measure
plasma lead are laborious and require special
and expensive equipment. However, this bio-
marker is a useful research tool in efforts to
understand and detect the health impacts of
environmental lead exposure.

In conclusion, we found that first-trimester
measures of fetal lead exposure—particularly
levels of lead in maternal plasma, but also levels of lead in maternal whole blood—were predic-
tive of adverse neurodevelopment later in life,
with an effect that was independent from that
of postnatal lead exposure and that was stronger
than the effects associated with second- or
third-trimester measures. This is of major
potential public health concern because lead
remains a widespread environmental health
hazard and current efforts at primary preven-
tion have focused almost entirely on childhood
rather than fetal exposure. If future research
confirms this finding, ascertaining women at
risk and identifying effective strategies for pre-
vention of fetal lead exposure may become an
important public health priority; moreover, it
can be necessary to consider prepregnancy
interventions, because our research suggests that
screening and intervention any later than the
first trimester may be too late to prevent the
largest fetal neurotoxic effects.

REFERENCES
Alfano DP, Petil TL. 1982. Neonatal lead exposure alters the
dendritic development of hippocampal dentate granule
Baghurst PA, McMichael AJ, Vimpani GV, Robertson EF, Clark
PD, Wijng NR. 1987. Determinants of blood lead concentra-
tions of pregnant women living in Port Pirie and surrounding
San Antonio, TX:Psychological Corporation.
Bellinger D, Levinson A, Waternaux C, Needelman H, Rabinovitch M.
1987. Longitudinal analyses of prenatal and postnatal lead
exposure and early cognitive development. N Enl J Med
316(17):1037–1043.
Bellinger DC, Needelman HL. 2003. Intellectual impairment and
Bellinger DC, Stiles NM, Needelman HL. 1992. Low-level lead
exposure, intelligence and academic achievement: a long-
Canfield RL, Henderson CR, Jr., Cory-Slechta DA, Cox C, Jurkta TA,
Lanphear BP. 2003. Intellectual impairment in children with
blood lead concentrations below 10 microg per deciliter.
CDC. 1991. Preventing Lead Poisoning in Young Children: A
Statement by the Centers for Disease Control. Atlanta,
GA:Centers for Disease Control.
Chuang HY, Schwartz J, Gonzales-Cossio T, Lugo MC, Palazuelos
E, Aro A, et al. 2001. Interrelations of levels in bone, venous
blood, and umbilical cord blood with exogenous lead
exposure through maternal plasma lead in peripartum
consequences of prenatal low level lead exposures to lead.
Neurotoxicol Teratol 11(2):95–104.
Dietrich KN, Kraftm KM, Bornschein RL, Hammond PB, Berger O,
Succop PA, et al. 1987. Low-level fetal lead exposure effect
on neurobehavioral development in early infancy. Pediatrics
Dietrich KN, Succop PA, Berger GS, Hammond PB, Bornschein
RL. 1991. Lead exposure and the cognitive development of
urban preschool children: the Cincinnati Lead Study cohort
level lead exposure in the prenatal and early preschool peri-
d: early preschool development. Neurotoxicol Teratol
9(3):259–270.
RJ. 1986. Intrauterine exposure to low levels of lead: the
Gomaa A, Hu H, Bellinger D, Schwartz J, Tsaih SW, Gonzalez-
risk factor for fetal neurotoxicity: a prospective study.
Goyer RA. 1990. Transplacental transport of lead. Environ Health
The influence of bone and blood lead on plasma lead levels
in environmentally exposed adults. Environ Health Perspect
Hu H. 1998. Bone lead as a new biologic marker of lead dose:
recent findings and implications for public health. Environ Health
Perspect 106(suppl 4):961–967.
Hu H, Hernandez-Avila M. 2002. Invited commentary: lead, bones,
women, and pregnancy—the poison within? Am J Epidemio
156(12):1088–1091.


