# Maternal Blood Lead Concentration, Diet During Pregnancy, and Anthropometry Predict Neonatal Blood Lead in a Socioeconomically Disadvantaged Population

**Lawrence M. Schell,[1] Melinda Denham,[2] Alice D. Stark,[3] Marta Gomez,[3] Julia Ravenscroft,[2] Patrick J. Parsons,[4] Aida Aydermir,[5] and Renee Samelson[6]**

[1]Department of Epidemiology, and [2]Department of Anthropology, University at Albany, State University of New York, Albany, New York, USA; [3]Bureau of Environmental and Occupational Epidemiology, New York State Department of Health, Troy, NY, USA; [4]Lead Poisoning/Trace Elements Laboratory Wadsworth Center, New York State Department of Health, Albany, New York, USA; [5]Department of Biostatistics, University at Albany, State University of New York, Albany, New York, USA; [6]Department of Obstetrics and Gynecology, Albany Medical Center, Albany, NY, USA

**To determine the influences of maternal diet and nutrition during pregnancy on the blood lead level of neonates, we conducted a study of mother–infant pairs from lower socioeconomic circumstances living in Albany County, New York. Maternal blood lead (MBPb), anthropometry, and diet were assessed in each trimester. Neonates' blood lead (NBPb) levels were low (geometric mean = 1.58 µg/dL), and none had elevated blood lead. More than 50% of the mothers had intakes below the recommended dietary allowances for zinc, calcium, iron, vitamin D, and kilocalories. As expected, MBPb was strongly and positively related to NBPb. Among the anthropometric measures of maternal nutritional status, variables measuring gain in weight and arm circumference were negatively related to NBPb. In multivariable models reflecting different analytic strageties and including MBPb, anthropometry, and sociodemographic characteristics, dietary intakes of iron and vitamin D were negatively related to NBPb. The effect of zinc varied substantially depending on model covariates. Effects of dietary constituents are difficult to distinguish, given the intercorrelated nature of nutrients in the diet. Nevertheless, the influences of maternal anthropometric variables, iron, and vitamin D on neonatal lead levels are clear in our analyses.** ***Key words:*** **anthropometry, calcium, children, diet, iron, lead, neonates, nutrition, zinc.**
***Environ Health Perspect*** **111:195–200 (2003). [Online 28 October 2002]**
**doi:10.1289/ehp.5592 available via** ***http://dx.doi.org/***

The average blood lead concentration among young children in the United States has decreased markedly since 1980 (Brody et al. 1994; Pirkle et al. 1994); but in many inner-city, socioeconomically disadvantaged communities, worrisome numbers of children continue to be diagnosed with elevated lead levels (Brown et al. 2000; Centers for Disease Control and Prevention 2001; LaFlash et al. 2000; Litaker et al. 2000). Lead is related to adverse health effects in children including interference with neurobehavioral development, reduced physical growth, impaired heme synthesis, kidney and liver failure, seizures, and even death (ATSDR 1988).

A child's lead burden begins before birth with lead transferred from maternal circulation and increases rapidly in the first few years of life, as exposure to environmental lead increases (ATSDR 1988; Brody et al. 1994; Pirkle et al. 1994). During pregnancy, lead is liberated from the maternal skeleton (Gulson et al. 1997) and transferred from mother to child *in utero*. It is useful to know the factors that may influence this transfer in order to manipulate them and reduce fetal exposure and its effects. Although many risk factors for lead exposure such as past maternal education or race/ethnicity cannot be altered, maternal diet during pregnancy and nutritional status can be. The goal of this investigation is to determine the influence of these two factors on the concentration of blood lead in the newborn in a socioeconomically disadvantaged population at risk for lead exposure.

## Materials and Methods

The Albany Pregnancy Infancy Lead Study (APILS), a prospective, longitudinal study, was initiated to address the question of nutrient–lead interaction and to explore the impact of early lead concentration on infant growth and development (the subject of other reports). The study was conducted in two phases that differed in follow-up protocol and lead concentration measurement methods: phase one from 1986 to 1992 and phase two from 1992 to 1998; both phases have been described elsewhere (Schell et al. 1997, 2000). This report is based on data from the second phase. All procedures for both studies were reviewed and approved by the Institutional Review Boards of the New York State Department of Health, Albany Medical Center and the State University of New York at Albany. Informed consent was obtained before data collection.

***Data collection and sample recruitment.*** The APILS sample was drawn from a socioeconomically disadvantaged population of pregnant women at risk for lead exposure due to poverty, urban residence in old, dilapidated housing, and close proximity to industrial and vehicular emissions. Pregnant women were recruited into the study if they sought prenatal care at either the Albany County Department of Health (ACDH) Clinic or the Albany Medical Center (AMC) Obstetrics Clinic. Once enrolled, a woman was seen for a study visit once during each trimester of her pregnancy. To be eligible for the study, a participant must *a*) have been a resident of Albany county; *b*) have been eligible for the Women, Infants and Children program (WIC; < 185% of poverty level); *c*) have been pregnant < 24 weeks; *d*) have planned to use either the ACDH or AMC clinics for prenatal care for at least two of the three trimesters of pregnancy (depending upon the timing of entry into the study); *e*) have permitted a cord blood sample to be taken; and, *f*) have planned to deliver at AMC and have the child followed at the ACDH or AMC pediatric clinic. Potential participants were excluded if they *a*) already had a child in the study; *b*) were unable to complete interviews in English (indicating insufficient linguistic ability to complete the cognitive performance assessment on maternal IQ tests needed to interpret infant development measures); *c*) were high-risk pregnancies (these were referred by clinic staff to a specialized clinic); or *d*) were pregnancies involving multiple fetuses. Newborns were not excluded on the basis of APGAR score or infant size. The sample used in this study represents all the participants recruited into the study between September 1992 and October 1998, when recruitment was completed.

Address correspondence to L.M. Schell, A&S 237, University at Albany, State University of New York, 1400 Washington Ave. Albany, NY 12222 USA. Telephone: (518) 442-4714. Fax: (518) 442-4563. E-mail: l.schell@albany.edu

We thank A. Cardemon, J. Crucetti, G. Deane, M. Egolstein, M. Gordon, W.A. Grattan, M. Heigel, M. Schmidt, J. Waldron, P. Weinbaum, M.E. White, and staff at the County of Albany Department of Health and at the Albany Medical College.

This study was supported by the National Institute of Environmental Health Sciences grant # R01-ES 05280.

Received 11 March 2002; accepted 20 September 2002.

***Measurement of blood lead.*** Maternal blood was drawn in each trimester during a regularly scheduled visit to the prenatal clinic and at delivery by a trained phlebotomist using a lead-free venous blood collection kit. The infant's cord blood (3 cc) was collected in the delivery room in most cases (90%). When cord blood could not be collected, venous blood (3 cc) was drawn in the neonatal nursery within the first 3 days (except in one case, drawn on day 8). All blood lead measurements were performed by the Wadsworth Center's Lead Poisoning/Trace Elements Laboratory, the New York State Department of Health's reference laboratory for the test. The analytic method for blood lead determination was electrothermal atomization atomic absorption spectrometry with Zeeman background correction; it has been fully validated and described in the literature (Parsons and Slavin 1993).

***Measurement of maternal diet and nutrition.*** During each prenatal interview, maternal diet for the month leading up to the interview was assessed using a modified version of the National Cancer Institute Food Questionnaire. The modifications allowed for reporting actual amounts consumed rather than small, medium, or large portions, and for specifying ethnic or foreign foods not included in the food list. A program was written to compute the 30-day intake of 37 macronutrients, vitamins, and minerals.

Maternal nutritional status with regard to serum Vitamin D (1,25-OH Vitamin D) was assessed in the second and third trimesters and was analyzed by Metpath Labs, Inc. (Teterboro, NJ). Maternal nutritional status also was assessed at each interview by anthropometric measures including weight, mid-upper arm circumference, and triceps skinfold thickness. Height and biepicondylar breadth of the humerus were measured once at the first prenatal visit. The latter measurement is an index of skeletal frame size (Frisancho and Flegel 1983). All measurements were made by one of the authors (L.M.S.) and nurses or graduate research assistants trained by that author using standard, published protocols (Cameron 1986; Lohman et al. 1988). Retraining sessions were performed at approximately 6-month intervals. Prepregnancy weight was obtained from the medical chart based on subject recall.

***The sample.*** Of the 317 eligible women, 71 terminated their pregnancies, discontinued participation, moved, or transferred care to another facility. In addition, blood from 26 newborns was not drawn at delivery for no medical reason, or was clotted and unanalyzable. These losses to the study left 220 newborns with a measured blood lead level at the time of delivery; thus, 220 is the maximum number used for analyses of relationships among mothers' and newborns' lead levels. This sample differs slightly from that used in a previous analysis of APILS data (Schell et al. 2000) because the previous analysis required two consecutive maternal blood lead levels during pregnancy. The blood lead levels of the sample mothers do not differ significantly from those excluded ($n$ = 97) during pregnancy or at delivery; excluded mothers had marginally higher second-trimester blood lead levels than included mothers (2.2 µg/dL and 2.0 µg/dL respectively), though this difference was not statistically significant.

The sample ($n$ = 220) is described in Table 1. Of the 220 mothers, nearly half identified their ethnicity/race as African-American. The median age of the women at time of enrollment was 22.6 years, and 31% of the women were 19 years of age or younger. Mean ages of women did not differ by ethnicity/race. Of the 220 mothers, 59% had completed high school, but 5% had not begun high school; 18% had one or more years of college. Most women (81%) had never been married or were separated or divorced. Median gravidity was three pregnancies, and median parity was one live birth. Sixty percent of the women reported that they were unemployed at the time of their first study visit. Forty-one percent reported that they had been unemployed during the 6 months preceding their first study visit (i.e., 1–5 months before they became pregnant, depending on when in the pregnancy they entered the study). Of the women who worked, most found employment in service occupations in which the hourly pay scale was near minimum wage.

For the analyses of relationships between maternal lead level during pregnancy and the blood lead level of the neonate, the sample sizes are reduced because of missing maternal blood lead observations. For further analysis of the relationship between dietary items and neonatal lead levels, the sample was restricted to those mother–neonate pairs with neonatal blood lead and dietary data available from interviews in all trimesters ($n$ = 89). In two cases missing prepregnancy body mass index (BMI; weight in kilograms/height in square centimeters) was predicted by regressing other maternal anthropometric measurements on prepregnancy BMI for the sample of 220 ($r^2$ = 0.96). Six additional cases were missing maternal lead levels and these could not be predicted well by multivariate regression, leaving a sample size of 83. These 83 subjects did not differ from excluded subjects ($n$ = 137) in second or third trimester weight; first-, second-, or third-trimester arm circumference or triceps skinfold thickness; maternal age; height; biepicondylar breadth of the humerus; prepregnancy weight or BMI; rate of arm circumference change from the first to second, first to third, or second to the third trimesters; ethnicity/race; education; marital status; first-, second-, and third-trimester intakes of fat, iron, and kilocalories; first- and second-trimester intakes of zinc, protein, vitamin D, and calcium; maternal lead level at birth; or newborn blood lead concentration. Excluded subjects had a lower first-trimester weight than did the 83 included subjects. Maternal intakes of zinc, protein, vitamin D, and calcium in the third trimester were significantly higher among excluded mother–infant pairs.

***Data analysis methods.*** Blood lead concentrations were log transformed due to nonnormal distributions. We first determined the relationships between newborn lead level and maternal factors (sociodemographic variables, biochemical measures of nutritional status, and maternal anthropometry) through bivariate analysis. Before testing, we noted that years of education are closely related to age in the subsample of women < 19 years of age ($r$ = 0.67, $p$ < 0.001, $n$ = 46). We constructed an education index (EI) of age-appropriate education that is independent of age ($r$ = 0.06, $p$ = 0.397, $n$ = 220) but closely related to maternal education ($r$ = 0.96, $p$ < 0.001, $n$ = 220). For persons < 19, EI = (years of education + 6)/age, and expresses the degree to which they are below or ahead of the age-appropriate year of schooling up to the completion of high school. For persons ≥ 19 years of age, presumably old enough to have completed high school, EI = (years of education + 6)/18 (18 is the age by which a person should have completed high school, allowing for one

**Table 1.** Characteristics of mothers at time of study enrollment ($n$ = 220).

| Characteristics | Values |
|---|---|
| Categorical variables, no. (%) | |
| Ethnicity/race | |
| African American | 103 (47) |
| White | 71 (32) |
| Hispanic | 32 (15) |
| Other | 14 (6) |
| Marital status | |
| Single | 157 (71) |
| Married | 42 (19) |
| Separated/divorced | 21 (10) |
| Currently employed (at time of enrollment) | |
| Yes | 84 (38) |
| No | 132 (60) |
| Not reported | 4 (2) |
| Previously employed (preceding 6 months) | |
| Yes | 127 (58) |
| No | 89 (41) |
| Not reported | 4 (2) |
| Continuous variables, mean ± SD | |
| Age at enrollment (years) | 23.5 ± 5.49 |
| Years of education | 11.5 ± 2.00 |
| Gravidity | 3.2 ± 2.18 |
| Parity | 1.2 ± 1.51 |
| Prepregnancy weight (kg) | 68.3 ± 20.15 |

extra year). Two persons who have completed two years of college, one 40 years old and one 25 years old, have the same EI value.

For analysis of maternal dietary effects we created two multivariable models (using the subsample of 83 mother–newborn pairs with complete dietary information) each containing a set of core control variables: prepregnancy BMI, ethnicity, age, education, anthropometry, second-trimester lead, delivery lead, and kilocalories. The latter was included to control for nutrient density. We did not include the following variables that were not related to neonatal blood lead in bivariate analysis: maternal arm circumference and triceps skinfold in first and third trimesters; weight in first, second, or third trimesters; maternal height; biepicondylar breadth of humerus; rate of change in maternal triceps skinfold (all trimesters); rate of change in maternal weight and arm circumference from first to second trimester; second- and third-trimester and delivery serum ferritin and vitamin D; use of dietary supplements during pregnancy; marital status; and employment status. High intercorrelation prevented including all significant anthropometric predictors of newborn lead in the models. Variables were chosen to minimize redundancy among anthropometrics while retaining full explanatory power. The first multivariate model also controlled for calcium (or vitamin D), iron, zinc, protein, and fat. To allow for the impact of intercorrelation among dietary variables in the multivariate model, we constructed a second model with the same core control variables, to which we added one dietary variable at a time, repeating the analysis with a different dietary variable each time. All calculations were performed using SPSS, Version 10.1 (SPSS, Chicago, IL). All $p$-values reported here are from two-tailed (nondirectional) tests.

Dietary intake of calcium, vitamin D, iron, zinc, protein, kilocalories, and fat were compared across trimesters and found not to differ significantly. Because multiple assessments of dietary intake provide a better estimate of true intake (Todd et al. 1983) and the intakes did not differ by trimester, we averaged each nutrient intake across all three trimesters to reduce intrasubject variation and random measurement error (Gibson 1990). In this sample, averaging intakes considerably reduced the variance of dietary intake measures. The variance of the averaged intakes of calcium, iron, fat, kilocalories, vitamin D, and zinc was, on average, only 58% of the individual trimester values.

## Results

Blood lead concentrations in this sample are low (Table 2). None of the newborns and only one mother had a blood lead concentration > 10 µg/dL in any single test. The effect of ethnicity/race is evident: African-American mothers and newborns have significantly higher blood lead concentrations than white mothers and newborns, except in the second trimester.

The strongest predictors of newborn blood lead concentration are maternal blood lead concentration in the first, second, and third trimesters and at delivery, as well as the change in maternal blood lead levels from the second trimester to delivery (Table 3). When the sample is restricted to mother–infant pairs with data on blood lead levels in every trimester and at delivery ($n$ = 79), the correlation coefficients are similar to or greater than those presented in Table 3 (data not shown). The correlation between mother's blood lead concentrations and the newborn's is similar in the African-American and white subsamples in every trimester but the first, where sample sizes also are the smallest. Infant blood lead levels are slightly, though significantly, lower than their mother's among both African-American and white subsamples. The transfer of blood lead is similar between the two subsamples when the higher level of blood lead in African-American mothers is taken into account. The difference between mother's and child's blood lead level expressed as percent of the mother's is 19% for whites and 25% for African Americans (a nonsignificant difference).

***Effects of maternal nutrition/anthropometric characteristics on newborn blood lead concentration.*** Several anthropometric measures of maternal nutritional status are related to newborn lead level. Greater rates of gain in maternal weight and arm circumference during the pregnancy are associated with lower blood lead concentration in the newborn (Table 4). Weaker, positive associations exist between blood lead concentrations in the newborn and several other measures of maternal size: prepregnancy BMI, prepregnancy weight, second-trimester arm circumference, and triceps skinfold thickness (Table 4). The correlations among these variables for the white and African-American subsamples are similar in direction and most are similar in magnitude to the correlations for

**Table 3.** Relationship of newborn blood lead level to maternal blood lead levels during pregnancy (Pearson correlations).

| | Newborn lead level at birth | | |
|---|---|---|---|
| Maternal lead | Total sample | Whites | African Americans |
| Trimester 1 | | | |
| $r$ | 0.66 | 0.46 | 0.71 |
| $p$-Value | < 0.001 | 0.006 | < 0.001 |
| No. | 94 | 35 | 45 |
| Trimester 2 | | | |
| $r$ | 0.53 | 0.53 | 0.53 |
| $p$-Value | < 0.001 | < 0.001 | < 0.001 |
| No. | 209 | 66 | 101 |
| Trimester 3 | | | |
| $r$ | 0.69 | 0.63 | 0.67 |
| $p$-Value | < 0.001 | < 0.001 | < 0.001 |
| No. | 198 | 65 | 92 |
| At delivery | | | |
| $r$ | 0.81 | 0.77 | 0.81 |
| $p$-Value | < 0.001 | < 0.001 | < 0.001 |
| No. | 211 | 70 | 98 |
| Change: second trimester to delivery | | | |
| $r$ | 0.37 | 0.32 | 0.38 |
| $p$-Value | < 0.001 | < 0.001 | < 0.001 |
| No. | 201 | 65 | 96 |

**Table 2.** Geometric mean (GM) of maternal blood lead measurements during pregnancy and infant's blood lead measurement at birth.

| | | Total sample | | Whites | | African-Americans | | Race/ethnicity |
|---|---|---|---|---|---|---|---|---|
| Lead (µg/dL) | No. | GM ± SD | Maximum[a] | GM ± SD | Maximum[a] | GM ± SD | Maximum[a] | $t$-test ($p$-value)[b] |
| Trimester 1 | 94 | 1.9 ± 1.68 | 12.9 | 1.6 ± 1.25 | 3.8 | 2.2 ± 1.61 | 7.5 | –3.06 (0.003) |
| Trimester 2 | 209 | 1.8 ± 1.63 | 10.4 | 1.6 ± 1.65 | 7.6 | 1.8 ± 1.62 | 6.6 | –1.92 (0.056) |
| Trimester 3 | 198 | 1.8 ± 1.65 | 9.4 | 1.5 ± 1.73 | 3.8 | 2.0 ± 1.54 | 7.5 | –3.86 (< 0.001) |
| Delivery (mother) | 211 | 2.2 ± 1.72 | 11.2 | 1.8 ± 1.72 | 5.6 | 2.5 ± 1.67 | 8.8 | –4.13 (< 0.001) |
| Delivery (infant) | 220 | 1.6 ± 1.78 | 6.9 | 1.3 ± 1.75 | 4.0 | 1.8 ± 1.79 | 6.5 | –3.18 (0.002) |

[a]Not log transformed. [b]$t$-Test comparing lead levels in white and African-American subsamples.

the sample as a whole, except for the effect of second-trimester triceps skinfold and the EI in the white subsample. The two anthropometric measures of skeletal size, maternal height, and biepicondylar breadth of the humerus are unrelated to newborn blood lead level. Other maternal anthropometric measures are unrelated to newborn lead level (data not shown): arm circumferences and triceps skinfolds in the first and third trimesters; maternal weight in the first, second, and third trimesters; rate of change in maternal triceps skinfold across all trimesters; rate of change in maternal weight and arm circumference from the first to second trimester.

***Effects of maternal dietary intakes on newborn blood lead concentration.*** Among women with nutrient intake data for each trimester ($n$ = 83), mean dietary intakes were significantly lower than the recommended dietary allowances (RDAs) for iron and vitamin D, significantly higher than the RDA for protein, and not significantly different from the RDAs for total caloric intake, calcium, and zinc (Table 5). More than 50% of women were below the RDA for zinc, calcium, iron, vitamin D, and kilocalories.

The first multivariable model, controlling for all other nutrients, shows significant negative relationships between neonatal blood lead and maternal intakes of iron and calcium, but not zinc, protein, or fat (Table 6). When vitamin D is substituted for calcium in the model, the results are similar [vitamin D: β coefficient = –0.013 (SE = 0.007), $t$ = –1.98, $p$ = 0.051]. The second multivariable model in which kilocalories are controlled and one other nutrient is entered into the model produces very similar results (Table 7) in terms of direction of effect and magnitude (β coefficients) for the effects of iron, vitamin D, and calcium except that zinc is a predictor of neonatal lead level in this analysis.

Serum ferritin, serum vitamin D, and the use of supplements were not significant covariates in either multivariable model (data not shown), nor were they significant in bivariate analyses used for model construction.

To estimate the impact of changes in maternal intake of significant micronutrients, we calculated change in newborn lead with changes in maternal intake of iron, calcium, and vitamin D, from one standard deviation below the mean intake to one standard deviation above it, using the model and sample described in Table 6. Among these nutrients, maternal iron intake has the largest impact on newborn lead. A two–standard-deviation decrease in iron (from 30.2 to 11.8 mg) is associated with a 0.51 µg/dL increase in newborn lead (29% of the mean of newborn lead, 1.72 µg/dL, $n$ = 83). A two–standard-deviation reduction in calcium (from 1,778 to 583 mg) is associated with an increase of 0.26 µg/dL in newborn lead (15% of the mean of newborn lead), whereas a two–standard-deviation reduction in maternal vitamin D intake, from 10.5 to 2.4 mg, is associated with a 0.18 µg/dL increase in newborn lead, 10% of the mean of newborn lead.

## Discussion

Although many of the variables that affect lead levels are difficult to change, maternal diet is potentially modifiable, especially during pregnancy when there may be a supportive environment for maternal and fetal health. However, determining dietary effects of specific nutrients is complicated by covariance among nutrients and wide variation in dietary intake due to intraindividual fluctuation and measurement error. The effect of the latter is apparent in our sample. For any nutrient, the variance of individual trimester intakes is close to twice the variance of the average of the three trimester intakes. The effect of averaging intakes is clear in the APILS sample: Individual nutrient intakes in any trimester are unrelated to newborn lead level in the sample with incomplete dietary data but also in the subsample of 83 mothers with complete dietary data used in our analysis. However, when the intakes across all trimesters are averaged and variances reduced, we observe the relationships reported here.

We employed two analytic approaches to deal with covariance among nutrients, and the results are consistent in both direction and magnitude. After adjustment for control variables (including maternal lead levels), higher maternal iron, calcium, and vitamin D intakes are related to lower newborn lead levels. Evidence for an impact of maternal zinc intake is equivocal. The effect of zinc intake may be absent in the analysis that includes other nutrients as covariates because of its high correlation with protein intake ($r$ = 0.89, $p$ < 0.001). The near universal use of dietary supplements in the sample used for the analysis of diet (78 of 83 mothers) suggests that the effects of dietary iron, calcium, and vitamin D seen here were not biased by differential supplement use. The lack of variability in supplement use also indicates that the absence of its statistical significance in either multivariable model is not a true test of its biologic effect.

Anthropometric measures of maternal nutritional status have a very strong and consistent effect on neonatal lead level: Measures of soft tissue size are positively related to higher newborn lead, whereas measures of gain (e.g., arm circumference during the later half of pregnancy) are related to lower newborn lead concentration. Because heavier women are unlikely to gain as much weight and arm circumference as smaller ones, gain becomes an especially

**Table 4.** Bivariate correlations (Pearson correlation coefficients) of newborn blood lead concentration at birth to maternal characteristics.

| Maternal variable | No. | All ethnicities/races $r$ ($p$-value) | White $r$ ($p$-value) | Black $r$ ($p$-value) |
|---|---|---|---|---|
| Age | 220 | 0.28 (< 0.001) | 0.25 (0.038) | 0.33 (0.001) |
| EI | 220 | –0.20 (0.003) | 0.25 (0.038) | –0.07 (0.522) |
| Arm circumference: 2nd trimester | 216 | 0.16 (0.023) | 0.22 (0.077) | 0.20 (0.043) |
| Triceps skinfold: 2nd trimester | 216 | 0.15 (0.033) | 0.03 (0.781) | 0.24 (0.014) |
| Prepregnancy weight | 213 | 0.16 (0.021) | 0.19 (0.121) | 0.16 (0.104) |
| Prepregnancy BMI | 213 | 0.19 (0.007) | 0.18 (0.147) | 0.21 (0.039) |
| Maternal weight rate of change: trimesters 1–3 | 94 | –0.31 (0.002) | –0.32 (0.068) | –0.19 (0.210) |
| Maternal weight rate of change: trimesters 1–3 | 206 | –0.32 (< 0.001) | –0.24 (0.056) | –0.38 (< 0.001) |
| Maternal arm circ rate of change: trimesters 1–3 | 94 | –0.21 (0.045) | –0.22 (0.213) | –0.22 (0.151) |
| Maternal arm circ rate of change: trimesters 2–3 | 206 | –0.32 (< 0.001) | –0.46 (< 0.001) | –0.27 (0.007) |

circ, circumference.

**Table 5.** Average nutritional intakes of women across three trimesters of pregnancy ($n$ = 83), compared with the 1989 recommended dietary allowances.

| Nutrients | Mean ± SD | Minimum | Maximum | < RDA No. | < RDA Percent | RDA |
|---|---|---|---|---|---|---|
| Calcium (mg) | 1180.7 ± 597.29 | 267.3 | 2817.0 | 50 | 60 | 1,200 |
| Vitamin D (mg) | 6.4 ± 4.02 | 0.5 | 21.9 | 69 | 83 | 10 |
| Iron (mg) | 21.0 ± 9.18 | 6.7 | 55.6 | 69 | 83 | 30 |
| Zinc (mg) | 13.7 ± 6.09 | 3.6 | 34.8 | 57 | 69 | 15 |
| Protein (g) | 93.8 ± 44.45 | 23.9 | 272.0 | 16 | 19 | 60 |
| Calories (kcal) | 2675.5 ± 1081.47 | 917.9 | 6394.1 | 45 | 54 | 2,500 |
| Fat (g) | 96.6 ± 43.70 | 22.0 | 246.6 | | | |

important and modifiable characteristic among smaller women. The relationship of maternal size to neonatal lead level mirrors the positive relationship of maternal caloric intake to neonatal lead level seen in our dietary analysis. The anthropometric measures of skeletal frame size (height and biepicondylar breadth) are not related to neonatal lead levels, suggesting that the size of the skeletal mass as a compartment for lead storage does not affect the transmission of lead from mother to fetus.

Our analysis of maternal diet provides new information on nutrient–lead interactions because it pertains to the transfer of lead from mother to fetus whereas most published research examines relationships of dietary intake and lead levels in either adults or children. In the APILS sample, higher maternal intakes of iron are associated with lower neonatal lead levels, a finding consistent with results from both experimental animal studies (Barton et al. 1978; Crowe and Morgan 1996; Hamilton 1978; Hashmi et al. 1989a, 1989b; Klauder and Petering 1975; Mahaffey-Six and Goyer 1972; Ragan 1977; Shukla et al. 1990; Singh et al. 1991; Suzuki and Yoshida 1979) and human studies (Cheng et al. 1998; Hammad et al. 1996; Mahaffey and Annest 1986; Markowitz et al. 1990; Szold 1974; Watson et al. 1980, 1986; Wright et al. 1999; Yip et al. 1981; Yip and Dallman 1984) that have shown negative associations between iron intake or iron status and blood lead levels. Despite this negative relationship between maternal dietary iron and infant lead levels, we found no significant association between mother's iron stores (serum ferritin) and newborn's blood lead levels in bivariate or multivariate analysis (data not shown), mirroring the results of Milman and colleagues (1988). Because 83% of dietary iron intakes in our sample were less than the RDA for pregnant women, our findings refer most closely to gravidae with suboptimal iron intakes.

Maternal dietary calcium and neonatal blood lead are inversely related in the APILS sample. These findings are consistent with results from carefully conducted cross-sectional studies finding higher calcium intakes related to lower lead levels (Cifuentes et al. 2000; Farias et al. 1996; Goyer 1997; Han et al. 2000; Hernandez-Avila et al. 1996; Hertz-Picciotto et al. 2000; Kostial et al. 1991; Mahaffey et al. 1986; Miller et al. 1990). In a longitudinal study of mother–neonate lead levels in Mexico (Rothenberg et al. 1996), greater maternal milk consumption during pregnancy was associated with lower neonatal lead. Thus, calcium intake appears to be related to lead both at low maternal lead levels, as in the APILS sample, and at higher levels, as in the Mexican sample. Whether the effect of calcium is present across the range of calcium intakes or is confined to mothers with intakes lower than the RDA could not be resolved here because the small size of the APILS sample precluded testing effects in subsamples below or above the RDA for calcium. Hertz-Piccioto and colleagues (2000) found an effect of calcium above the RDA, but other studies have not investigated this or have not found it.

The similar effects of maternal dietary calcium and vitamin D on neonatal lead levels that we observe in the APILS sample are reasonable, given the coincidence of sources of both nutrients in maternal diets (reflected in the high correlation between them). Our results also are consistent with the finding that adjustment for vitamin D levels removes the effect of calcium on blood lead among a sample of mature men (Cheng et al. 1998).

Our results show that calories are positively related to lead level. Insofar as diet serves as a major vehicle for the ingestion of lead in the United States, our finding is consistent with calories' being an indicator of dietary quantity. This finding also agrees with several other studies with multivariable analyses that take other nutrients into account (Hammad et al. 1996; Lucas et al. 1996) although it does not agree with all (Mahaffey et al. 1986; Mooty et al. 1975).

Our findings that maternal lead levels during pregnancy are strongly related to neonatal lead level are consonant with previously published studies (Amitai et al. 1999; Angell and Lavery 1982; Campagna et al. 1999; Carbone et al. 1998; Chuang et al. 2001; Dietrich et al. 1987; Graziano et al. 1990; Lauwerys et al. 1978; McMichael et al. 1988; Nashashibi et al. 1999; Navarrete-Espinosa et al. 2000). The correlation in the APILS sample between maternal and neonatal lead levels at parturition is well within the published range from 0.36 (Amitai et al. 1999) to 0.92 (Graziano et al. 1990). The strong relationship between maternal lead levels and ethnicity/race in the APILS sample is consistent with the distribution of lead levels in the United States. Further, this relationship is reflected in the multivariate analyses where ethnicity/race is not significantly related to neonatal lead when maternal lead levels also are in the model. This reflects the difference in lead levels by maternal ethnicity/race. The large impact of maternal blood lead levels points to the need for interventions before pregnancy to reduce lead transmission from mother to offspring.

Managing maternal diets during pregnancy to ensure intakes of calcium, vitamin D, and iron at or above the RDA is warranted by our results. For example, a two–standard-deviation increase in the intake of iron and calcium resulted in a decrease in neonatal blood lead level of 0.77 μg/dL or 45% of the mean

**Table 6.** Relationship of maternal nutrition, anthropometry, lead levels, and diet to newborn's blood lead level.

| Terms | β coefficient | β SE | Standardized β | *t*-Value | *p*-Value |
|---|---|---|---|---|---|
| Constant | –0.473 | 0.269 | | –1.76 | 0.083 |
| Age | 0.006 | 0.004 | 0.07 | 1.35 | 0.183 |
| Education index | 0.095 | 0.229 | 0.02 | 0.41 | 0.680 |
| Ethnicity/race (black = 1, nonblack = 0) | –0.009 | 0.045 | –0.01 | –0.20 | 0.845 |
| Prepregnancy BMI | 0.008 | 0.005 | 0.13 | 1.63 | 0.109 |
| Triceps skinfold: second trimester | –0.008 | 0.004 | –0.17 | –2.14 | 0.036 |
| Arm circ rate of change: trimester 2–3 | –2.989 | 0.888 | –0.14 | –3.37 | 0.001 |
| Lead at delivery (μg/dL) | 0.798 | 0.061 | 0.82 | 13.05 | 0.000 |
| Lead at second trimester (μg/dL) | 0.112 | 0.059 | 0.11 | 1.88 | 0.065 |
| Caloric intake (kcal) | 0.0003 | 0.0001 | 0.63 | 3.65 | 0.001 |
| Iron intake (mg) | –0.016 | 0.008 | –0.30 | –2.10 | 0.040 |
| Calcium intake (mg) | –0.0001 | 0.0001 | –0.15 | –2.08 | 0.042 |
| Zinc intake (mg) | –0.0005 | 0.012 | –0.01 | –0.04 | 0.969 |
| Fats intake (g) | –0.002 | 0.001 | –0.22 | –1.78 | 0.079 |
| Protein intake (g) | 0.0002 | 0.002 | 0.02 | 0.13 | 0.897 |

circ, circumference. Model: $r = 0.95$, $r^2 = 0.90$, $n = 83$.

**Table 7.** Relationship of maternal dietary intakes during pregnancy to newborn's blood lead level: effects of single dietary variables when added to the core model[a] of control variables.

| Core model plus single nutrient | β coefficient | β SE | Standardized β | *t*-Value | *p*-Value |
|---|---|---|---|---|---|
| Maternal iron intake (mg) | –0.014 | 0.005 | –0.26 | –3.06 | 0.003 |
| or Maternal zinc intake (mg) | –0.022 | 0.007 | –0.27 | –3.24 | 0.002 |
| or Maternal vitamin D intake (mg) | –0.014 | 0.007 | –0.11 | –2.11 | 0.038 |
| or Maternal fats intake (g) | –0.002 | 0.001 | –0.17 | –1.41 | 0.162 |
| or Maternal protein intake (g) | –0.002 | 0.001 | –0.22 | –1.69 | 0.096 |
| or Maternal calcium intake (mg) | –0.0001 | 0.0001 | –0.12 | –1.73 | 0.088 |

Core model: $r = 0.93$, $r^2 = 0.87$, $n = 83$.
[a]The core model controls for age, education index, ethnicity/race, prepregnancy BMI, second-trimester triceps skinfold, rate of change of arm circumference from the second to third trimester, and mother's blood lead at delivery and during the second trimester.

neonatal level. A further opportunity for lowering lead levels by adjusting nutrient intakes may occur during infancy, and a future report from this data set will address this problem.

## References


ATSDR. 1988. The Nature and Extent of Lead Poisoning in Children in the United States: A Report to Congress. Atlanta, GA:Agency for Toxic Substances and Diseases Registry.

Amitai Y, Katz D, Lifshitz M, Gofin R, Tepferberg M, Almog S. 1999. Prenatal lead exposure in Israel: an international comparison. Isr Med Assoc J 1(4):250–253.

Angell NF, Lavery PJ. 1982. The relationship of blood lead levels to obstetric outcome. Am J Obstet Gynecol 142:40–46.

Barton JC, Conrad ME, Harrison N. 1978. Effects of iron on the absorption and retention of lead. J Lab Clin Med 91:536–547.

Brody DJ, Pirkle JL, Kramer RA, Flegal KA, Matte TD, Gunter EW, et al. 1994. Blood lead levels in the US population. phase 1 of the Third National Health and Nutrition Examination Survey (NHANES III, 1988–1991). JAMA 272(4):277–283.

Brown MJ, Shenassa E, Matte TD, Catlin SN. 2000. Children in Illinois with elevated blood lead levels, 1993–1998, and lead-related pediatric hospital admissions in Illinois, 1993–1997. Public Health Rep 115(6):532–536.

Cameron N. 1986. The methods of auxological anthropometry. In: Human Growth: Methodology; Ecological, Genetic, and Nutritional Effects on Growth (Falkner F, Tanner JM, eds). New York:Plenum Press, 3–46.

Campagna D, Huel G, Girard F, Sahuquillo J, Blot P. 1999. Environmental lead exposure and activity of delta-aminolevulinic acid dehydratase (ALA-D) in maternal and cord blood. Toxicology 134(2–3):143–152.

Carbone R, Laforgia N, Crollo E, Mautone A, Iolascon A. 1998. Maternal and neonatal lead exposure in southern Italy. Biol Neonate 73(6):362–366.

Centers for Disease Control and Prevention. 2001. Trends in blood lead levels among children—Boston, Massachusetts, 1994–1999. Morb Mortal Wkly Rep 50(17):337–339.

Cheng Y, Willet WC, Schwartz J, Sparrow D, Weiss S, Hu H. 1998. Relation of nutrition to bone lead and blood lead levels in middle-aged to elderly men. Am J Epidemiol 147(12):1162–1174.

Cifuentes E, Villanueva J, Sanin LH. 2000. Predictors of blood lead levels in agricultural villages practicing wastewater irrigation in central Mexico. Int J Occup Environ Health 6(3):177–182.

Chuang H-Y, Schwartz J, Gonzales-Cossio T, Lugo MC, Palazuelos E, Aro A, et al. 2001. Interrelations of lead levels in bone, venous blood, and umbilical cord blood with exogenous lead exposure through maternal plasma lead in peripartum women. Environ Health Perspect 109:527–532.

Crowe A, Morgan EH. 1996. Interactions between tissue uptake of lead and iron in normal and iron-deficient rats during development. Biol Trace Elem Res 52(3):249–261.

Dietrich KN, Krafft KM, Bornschein RL, Hammond PB, Berger OG, Succop PA, et al. 1987. Low-level fetal lead exposure effect on neurobehavioral development in early infancy. Pediatrics 80(5):721–730.

Farias P, Borja-Aburto VH, Rios C, Hertz-Piciotta I, Rojas-Lopez M, Chavez-Ayala R. 1996. Blood lead levels in pregnant women high and low socioeconomic status in Mexico City. Environ Health Perspect 104:1070–1074.

Frisancho AR, Flegel PN. 1983. Elbow breadth as a measure of frame size for US males and females. Am J Clin Nutr 37:311–314.

Gibson RS. 1990. Principles of Nutritional Assessment. New York:Oxford University Press.

Goyer RA. 1997. Toxic and essential metal interactions. Annu Rev Nutr 17:37–50.

Graziano JH, Popovac D, Factor-Litvak P, Shrout P, Kline JK, Murphy MJ, et al. 1990. Determinants of elevated blood lead during pregnancy in a population surrounding a lead smelter in Kosovo, Yugoslavia. Environ Health Perspect 89:95–100.

Gulson BL, Jameson CW, Mahaffey KR, Mizon KJ, Korsch MJ, Vimpani GV. 1997. Pregnancy increases mobilization of lead from maternal skeleton. J Lab Clin Med 130(1):51–62.

Hamilton DL. 1978. Interrelationship of lead and iron retention in iron deficient mice. Toxicol Appl Pharmacol 46:651–661.

Hammad TA, Sexton M, Langenberg P. 1996. Relationship between blood lead and dietary iron intake in preschool children: a cross-sectional study. Ann Epidemiol 6:30–33.

Han S, Pfizenmaier DH, Garcia E, Eguez ML, Ling M, Kemp FW, et al. 2000. Effects of lead exposure before pregnancy and dietary calcium during pregnancy on fetal development and lead accumulation. Environ Health Perspect 108:527–531.

Hashmi NS, Kachru DN, Tandon SK. 1989a. Interrelationship between iron deficiency and lead intoxication (part 1). Biol Trace Elem Res 22(3):287–297.

Hashmi NS, Kachru DN, Khandelwal S, Tandon SK. 1989b. Interrelationship between iron deficiency and lead intoxication (part 2). Biol Trace Elem Res 22(3):299–307.

Hernandez-Avila M, Gonzalez-Cossio T, Palazuelos E, Romieu I, Aro A, Fishbein E, et al. 1996. Dietary and environmental determinants of blood and bone lead levels in lactating postpartum women living in Mexico City. Environ Health Perspect 104:1076–1083.

Hertz-Picciotto I, Schramm M, Watt-Morse M, Chantala K, Anderson J, Osterloh J. 2000. Patterns and determinants of blood lead during pregnancy. Am J Epidemiol 152(9):829–837.

Klauder DS, Petering HG. 1975. Protective value of dietary copper and iron against some toxic effects of lead in rats. Environ Health Perspect 12:77–80.

Kostial K, Dekanic D, Telisman S, Blanusa M, Duvancic S, Prpic-Majic D, et al. 1991. Dietary calcium and blood lead levels in women. Biol Trace Elem Res 28(3):181–185.

LaFlash S, Joosse-Coons M, Havlena J, Anderson HA. 2000. Wisconsin children at risk for lead poisoning. Wisc Med J 99(8):18–22.

Lauwerys R, Buchet JP, Roels H, Hubermont G. 1978. Placental transfer of lead, mercury, cadmium, and carbon monoxide in women. I. Comparison of the frequency distributions of the biological indices in maternal and umbilical cord blood. Environ Res 15(2):278–289.

Litaker D, Kippes CM, Gallagher TE, O'Connor ME. 2000. Targeting lead screening: The Ohio Lead Risk Score. Pediatrics 106(5):E69.

Lohman TG, Roche AF, Martorell R. 1988. Anthropometric Standardization Reference Manual. Champaign, IL:Human Kinetics Books.

Lucas SR, Sexton M, Langenberg P. 1996. Relationship between blood lead and nutritional factors in preschool children: a cross-sectional study. Pediatrics 97(1):74–78.

Mahaffey KR, Annest JL. 1986. Association of EP with blood lead level and iron status in the second National Health and Nutrition Examination Survey. Environ Res 41:327–328.

Mahaffey KR, Gartside PS, Glueck CJ. 1986. Blood lead levels and dietary calcium intake in 1- to 11-year-old children: The second National Health and Nutrition Examination Survey, 1976 to 1980. Pediatrics 78(2):257–262.

Mahaffey-Six KM, Goyer RA. 1972. The influence of iron deficiency on tissue content and toxicity of ingested lead in the rat. J Lab Clin Med 79(1):128–136.

Markowitz ME, Rosen JF, Bijur PE. 1990. Effect of iron deficiency on lead excretion in children with moderate lead intoxication. J Pediatr 116:360–364.

McMichael AJ, Baghurst PA, Wigg NR, Vimpani GV, Robertson EF, Roberts RJ. 1988. Port Pirie Cohort Study: environmental exposure to lead and children's abilities at the age of four years. N Engl J Med 319(8):468–475.

Miller GD, Massaro TF, Massaro EJ. 1990. Interactions between lead and essential elements: a review. Neurotox 11:99–120.

Milman N, Christensen JM, Ibsen KK. 1988. Blood lead and erythrocyte zinc protoporphyrin in mothers and newborn infants. Eur J Pediatr 147:71–73.

Mooty J, Ferrand CF, Harris P. 1975. Relationship of diet to lead poisoning in children. Pediatrics 55(5):636–639.

Nashashibi N, Cardamakis E, Bolbos G, Tzingounis V. 1999. Investigation of kinetic of lead during pregnancy and lactation. Gynecol Obstet Invest 48(3):158–162.

Navarrete-Espinosa J, Sanin-Aguirre LH, Escandon-Romero C, Benitez-Martinez G, Olaiz-Fernandez G, Hernandez-Avila M. 2000. Lead blood levels in mothers and newborn infants covered by the Mexican Institute of Social Security. Salud Publica Mex 42(5):391–396.

Parsons P, Slavin W. 1993. A rapid zeeman graphite-furnace atomic absorption spectrometric method for the determination of lead in blood. Spectrochim Acta B 48B:925–939.

Pirkle JL, Brody DJ, Gunter EW, Kramer RA, Paschal DC, Flegal KM, et al. 1994. The decline in blood lead levels in the United States: the National Health and Nutrition Examination Surveys (NHANES). JAMA 272(4):284–291.

Ragan HA. 1977. Effects of iron deficiency on the absorption and distribution of lead and cadmium in rats. J Lab Clin Med 90(4):700–706.

Rothenberg SJ, Karchmer S, Schnaas L, Perroni E, Zea F, Salinas V, et al. 1996. Maternal influences on cord blood lead levels. J Expo Anal Environ Epidemiol 6(2):211–227.

Schell LM, Czerwinski S, Stark AD, Parsons PJ, Gomez M, Samelson R. 2000. Variation in blood lead and hematocrit levels during pregnancy in a socioeconomically disadvantaged population. Arch Environ Health 55(2):134–140.

Schell LM, Stark AD, Gomez MI, Grattan WA. 1997. Blood lead level by year and season among poor pregnant women. Arch Environ Health 52(4):286–291.

Shukla A, Agarwal KN, Shukla GS. 1990. Effect of latent iron deficiency on the levels of iron, calcium, zinc, copper, manganese, cadmium and lead in liver, kidney and spleen of growing rats. Experientia 46(7):751–752.

Singh US, Saxena DK, Singh C, Murthy RC, Chandra SV. 1991. Lead-induced fetal nephrotoxicity in iron-deficient rats. Reprod Toxicol 5(3):211–217.

Suzuki T, Yoshida A. 1979. Effect of dietary supplementation of iron and ascorbic acid on lead toxicity in rats. J Nutr 109(6):983–988.

Szold PD. 1974. Plumbism and iron deficiency. N Engl J Med 290:520.

Todd KS, Hudes M, Calloway DH. 1983. Food intake measurement: problems and approaches. Am J Clin Nutr 37(1):139–146.

Watson WS, Hume R, Moore MR. 1980. Oral absorption of lead and iron. Lancet 2:236–237.

Watson WS, Morrison J, Bethel MIF, Baldwin NM, Lyon DTB, Dobson H, et al. 1986. Food iron and lead absortion in humans. Am J Clin Nutr 44:248–256.

Wright RO, Shannon MW, Wright RJ, Hu H. 1999. Association between iron deficiency and low-level lead poisoning in an urban primary care clinic. Am J Public Health 89(7):1049–1053.

Yip R, Dallman PR. 1984. Developmental changes in EP: Roles of iron deficiency and lead toxicity. J Pediatr 104:710–713.

Yip R, Norris TN, Anderson AS. 1981. Iron status of children with elevated blood lead concentration. J Pediatr 53:597–646.