Relationship Between Blood Lead and Nutritional Factors in Preschool Children: A Cross-sectional Study

Susan R. Lucas, MS*; Mary Sexton, PhD, MPH*; and Patricia Langenberg, PhD*

ABSTRACT. *Objective.* **The purpose of this study was to assess the relationships between selected nutritional factors and blood lead levels of preschool children.**

Methodology. **Data on 296 children, aged 9 to 72 months, who were cared for at the University of Maryland at Baltimore Pediatric Ambulatory Center were examined in this cross-sectional study. Nutritional status, socioeconomic aspects, medical history, and potential sources of lead exposure were assessed. Blood samples were evaluated for levels of blood lead, serum iron (ferritin), free erythrocyte photoporphyrin, calcium, and hematocrit.**

Results. **The average blood lead level was 11.4 μg/dL. Multicollinearity of nutritional factors was addressed using regression techniques. After adjusting for confounders, significant positive associations with blood lead were found for total caloric intake ($P = .01$) and dietary fat ($P = .05$).**

Conclusions. **The findings of this study suggest that even when behavioral and environmental exposures to lead were statistically controlled, total caloric intake and dietary fat each had an independent and significant association with the level of blood lead.** ***Pediatrics*** **1996;97: 74–78;** ***blood lead, dietary fat, children.***

ABBREVIATIONS. CDC, Centers for Disease Control and Prevention; BPb, blood lead; PAC, pediatric ambulatory clinic; FEP, free erythrocyte photoporphyrin.

Lead is a heavy metal with no known value in humans. Lead poisoning continues to occur in children, resulting in death and possibly long-term learning disorders and behavioral problems.[1–3] The Centers for Disease Control and Prevention (CDC) classify a blood lead (BPb) level of 10 μg/dL as the level at which lead poisoning has occurred.[4] The Agency for Toxic Substances and Disease Registry estimated that in 1984, 17% of American preschool children had BPb levels that exceeded 15 μg/dL.[5]

Lead poisoning among children in the United States is known to occur primarily in urban areas where economically deprived families live in deteriorating older housing. The importance of eliminating the environmental exposures to lead is recognized, but these changes are dependent, in large part, on legislation. Much legislation has been passed including the outlawing of lead in gasoline and federal funding for lead removal. In addition, the public health field has looked toward other means of treatment and prevention including examination of nutritional influences.[1] In the early 1970s, dietary factors emerged as promising secondary preventive measures against lead poisoning in children, but knowledge was not firmly established.[6] The most attention at that time was focused on dietary calcium and iron, which are now used fairly extensively as clinical interventions. However, evidence from more recent studies, although not consistent, suggests that four additional dietary factors may also be related to increased BPb levels, but have not been confirmed in children living in situations where they are at high risk for lead toxicity;[7–15] these are total calories, fats, proteins, and carbohydrates. The independence of the effects of these four nutritional components from calcium and iron has not been addressed.

To establish that results from experimental studies in animals apply to free-living individuals is difficult. For example, laboratory-controlled experiments with animals related to the effects of calcium on BPb have an advantage in being able to isolate single nutrients, where the presence of other nutrients does not have to be analyzed. Such experiments, while clarifying with respect to one factor, have the disadvantage that they have not taken into consideration the complexity of the human diet. The studies of diet and BPb conducted with free-living individuals have limitations of their own. Because most nutritional components that are consumed by humans are highly correlated with one another, it is important that when one nutrient is being studied, adjustments be made for other key nutrients. Yet most human studies have not done this.

The objective of this study was to determine whether total caloric intake, dietary fat, dietary protein and carbohydrates are associated with BPb in children while simultaneously controlling for other nutrients and environmental exposures.

METHODS

A total of 307 preschool children were enrolled as a convenience sample from the University of Maryland at Baltimore Pediatric Ambulatory Clinic (PAC). Informed consent was obtained from guardians (mostly the mother) who volunteered to answer a questionnaire and on behalf of their children to be participants in the study. These subjects were selected from a population that was predominantly black and lived in a low-income, urban community in downtown Baltimore. Eleven subjects were excluded: three because they were older than 6 years of age and eight because of missing information on the questionnaire. Venous blood was drawn and BPb levels were measured. Questionnaires addressing socioeconomic factors, medical history, and potential sources of

From the University of Maryland School of Medicine, Department of Epidemiology and Preventive Medicine.

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Reprint requests to (S.R.L.) 13532 Huntley Place, Silverdale, WA 98383.

lead exposure were administered by trained interviewers to the guardians of all subjects. Nutritional status was assessed using a modified version of the Gladys Block food frequency questionnaire.[16] The questionnaire, which was developed and validated for use in adults, was modified for use in children but has not been validated for them. Nutritional values obtained from the questionnaire could rank the children on nutritional intake, although the raw values may be inaccurate.

Two summary variables of lead exposure were created for the analysis. The first summary variable, referred to as the behavioral exposure variable, included behaviors that would increase exposure to lead such as fingers or nonfood in mouth, swallowing clay, paint, plaster, dirt, or other odd substances, as well as whether the child played outdoors or had siblings or friends with high BPb levels. Although no samples, such as paint chips, were taken from the homes, questionnaire information was used to assess environmental exposure. A second summary variable, referred to as the environmental exposure variable, included conditions of the subjects' houses that might contribute to increased BPb levels, such as lead-based paint in the house, crumbling paint or plaster, window sills in poor repair, lead pipes for drinking water, or having anyone else in the household identified with high BPb. Each question required a yes or no response. If the question was answered "yes," then a value of 1 was assigned. Otherwise a "0" was assigned. The total was the value of the summary variable.

Unadjusted correlations of BPb with the four dietary nutrients expressed as percent of total calories are shown in Table 1. Total caloric intake, dietary fat, and carbohydrate intake were significantly associated with BPb level with correlations above 0.20. Carbohydrate intake was negatively associated while the other nutritional factors were positively associated with BPb.

Candidate covariates, based on their crude association with the outcome variable BPb level, were examined; those that had $P < .20$ for the correlation coefficients were selected for possible inclusion in the models (Table 2). For each model, the variables of total caloric intake, dietary fat, dietary protein, carbohydrates, child's age (in months), child's weight (in pounds), maternal education, behavioral exposure, environmental exposure, dietary calcium, dietary iron, and free erythrocyte photoporphyrin qualified for inclusion. Other variables were also tested for inclusion in the models because they were shown to be confounders in previous studies. These additional variables were gender, body mass index, race, vitamin D, thiamin, and phosphorus.

Multiple linear regression analyses were performed. It should be noted that all four nutrient variables could not be included in a multiple linear regression model because the three nutrients, fats, proteins, and carbohydrates, sum to total calories, and thus collinearity would be present. Because of the collinearity, additional models were used to examine the independent effect of each nutrient on BPb level while controlling for all but one of the others. Multiple linear regression model one included three of the nutrients–dietary fat, dietary protein, and carbohydrates. Model two included total caloric intake, dietary fat, and dietary protein. In this latter model, fats and proteins were expressed as percent of calories to alleviate problems of collinearity. Logistic regression analyses were performed to assess the extent to which the nutritional components were associated with BPb levels of ≥10 μg/dL.

RESULTS

The demographic characteristics of the population are given in Table 3. The overall gender distribution was nearly even with just over half of the subjects being males. A majority of the study population was black as was expected because of the inner-city location of the clinic. The age range was from 9 months to 72 months, with the mean age being 26.7 months. The BPb levels of the children had a range from 1 to 55 μg/dL with a mean of 11.4 μg/dL (Figure).

TABLE 1. Unadjusted Correlations Between Blood Lead Level and Nutritional Variables for Pediatric Subjects at the University of Maryland at Baltimore Pediatric Ambulatory Center

Nutritional Variable	Correlation Coefficient (R)	P Value
Total calories	0.25	<.01
Percent calories from carbohydrates	−0.21	<.01
Percent calories from fats	0.22	<.01
Percent calories from proteins	0.10	.08

TABLE 2. Variables Tested for Inclusion in the Multiple Linear Regression Models With Blood Lead (μg/dL) as the Dependent Variable

Total caloric intake	Dietary calcium
Dietary fat	Dietary iron
Dietary protein	Free erythrocyte photoporphyrin
Carbohydrates	Gender
Child's age	Body mass index
Child's weight	Race
Maternal education	Vitamin D
Behavioral exposure	Thiamin
Environmental exposure	Phosphorus

TABLE 3. Demographics of the Pediatric Population Studied From the University of Maryland at Baltimore Pediatric Ambulatory Clinic

Variable	N	Percent
Gender		
Male	158	53
Female	138	47
Race		
Black	243	82
Non-black	53	18
Age		
(Mean = 26.7 months, range 9–72 months)		
≤24 months	148	50
>24 months	148	50
Maternal Education		
Less than high school	127	43
High school graduate	169	57
Blood Lead Level		
(Mean = 11.4 μg/dL, Range 1–55 μg/dL)		
<10 μg/dL	144	49
≥10 μg/dL	152	51

The first multiple linear regression model, model one, included dietary fat in grams, carbohydrates in grams, and dietary protein in grams (Table 4). In addition to these nutrient variables, adjustment was made for maternal education, environmental exposure, behavioral exposure, child's age, and FEP. Dietary protein was not associated with BPb level when fats and carbohydrates were statistically controlled ($P = .24$). Carbohydrates were also not associated with BPb level when fats and proteins were statistically controlled ($P = .41$). Dietary fat, however, did have a significant positive independent association with BPb ($P = .05$).

In model two, total caloric intake was significantly associated with BPb when controlling for percent calories due to fats and proteins (Table 5). As in model one, dietary fat was again positively associated with BPb ($P = .04$) and dietary protein was not significantly associated with BPb ($P = .42$). Adjustments were made for maternal education, environmental exposure, behavioral exposure, FEP, and the child's age.

Logistic regression analysis was used to examine relationships between the nutrients and BPb. At 10 μg/dL and above, [the level at which children are considered at risk for lead poisoning] dietary fat was weakly associated ($P = .09$) when other nutrients,

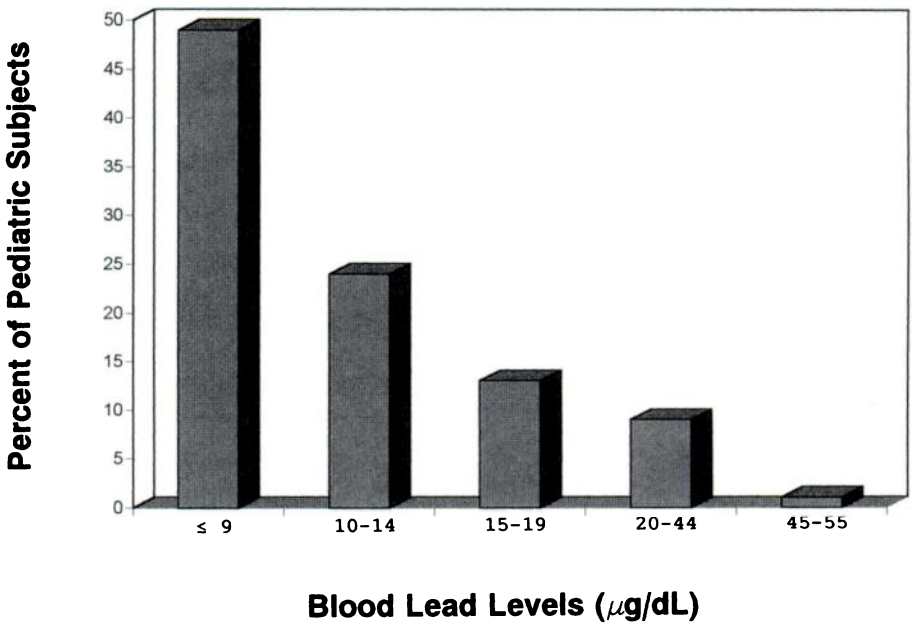

Figure. Blood lead levels of study subjects.

TABLE 4. Multiple Linear Regression Model 1 for Blood Lead Level (μg/dL)*

Variable	Coefficient	SE	*P* Value
Intercept	2.70		
Dietary fat (g)	0.27	0.14	.05
Dietary protein (g)	−0.20	0.17	.25
Carbohydrates (g)	0.04	0.04	.41
Free erythrocyte photoporphyrin	0.34	0.08	< .01
Maternal education†	−0.21	0.07	< .01
Environmental exposure‡	0.10	0.03	< .01
Behavioral exposure¶	0.12	0.04	< .01
Child's age (months)	0.01	0.01	.06

* N = 296; R^2 = 0.23.
† 0 = high school grad; 1 = high school grad and above.
‡ Scale range from 1–5 based on total individual environmental exposures to lead.
¶ Scale range from 1–5 based on total individual behavioral exposures to lead.

TABLE 5. Multiple Linear Regression Model 2 for Blood Lead Level (μg/dL)*

Variable	Coefficient	SE	*P* Value
Intercept	2.25		
Total caloric intake (kcal)	0.01	0.01	.01
Percent calories from fats	1.06	0.52	.04
Percent calories from proteins	−1.04	1.28	.42
Free erythrocyte photoporphyrin	0.34	0.08	< .01
Maternal education†	−0.20	0.07	< .01
Environmental exposure‡	0.09	0.03	< .01
Behavioral exposure¶	0.12	0.04	< .01
Child's age (months)	0.01	0.01	.20

* N = 296; R^2 = 0.24.
† 0 = non-high school grad; 1 = high school grad and above.
‡ Scale range from 1–5 based on total individual environmental exposures to lead.
¶ Scale range from 1–5 based on total individual behavioral exposures to lead.

demographics and other variables were controlled (not shown). At 15 μg/dL and above, dietary fat was significantly associated P = .03 (Table 6). Proteins and carbohydrates were not significant at the .05 level. In a logistic regression model when the other three nutrients were controlled, total caloric intake was not associated with BPb at either level of categorization (not shown).

DISCUSSION

A strength of this study of nutrition and BPb was its focus on young children. Most other studies have been conducted with animals or adults and results may not be applicable to children. According to the CDC Guidelines only about half of the PAC subjects have an acceptable BPb level.[4] Data regarding relationships of BPb and diet from such a high-risk group are particularly informative in considering recommendations for dietary interventions in young patients with elevated BPb levels.

The analytical approach in the present study was to control key nutritional factors so that the independent effects of calories, fats, proteins, and carbohydrates could be evaluated. Additionally, self-reports were used for an extensive assessment of exposures to lead from which two summary variables were constructed. Thus this study was able to control statistically for some lead exposures when examining nutritional factors. Even though the summary exposure variables remain incomplete measures, they provided a more comprehensive adjustment for lead exposures than those used in most previous studies.[20,21]

Findings from animal studies support the relationship between high fat diets and lead absorption found in this study of children.[10,11,14,15] A possible biological mechanism that could explain this association involves the breakdown of dietary fat into monoglycerides and other constituents that begins when bile acids are secreted to aid in the digestion and absorption of fat.[17] Bile plays an important role in absorption of lead from the gastrointestinal tract.[18,19] Cikrt et al showed, for example, that when lead was administered intraduodenally to rats with intact bile ducts, a greater percentage of lead was absorbed than in rats with cannulated bile ducts.[18]

TABLE 6. Results of Logistic Regression Analysis for the Association of Nutritional Components With Blood Lead Level ≥15 μg/dL*

Variable	Coefficient	χ^2	P Value
Intercept	−2.38		
Dietary fat (g)	0.01	4.61	.03
Dietary protein (g)	−0.01	3.09	.08
Carbohydrate (g)	0.01	0.07	.79
Free erythrocyte photoporphyrin	1.22	11.88	< .01
Environmental exposure†	0.39	8.01	< .01
Behavioral exposure‡	0.47	6.07	.01
Child's weight (lbs)	−0.01	0.01	.97

* N = 296.
† Scale range from 1–5 based on total individual environmental exposures to lead.
‡ Scale range from 1–5 based on total individual behavioral exposures to lead.

According to these authors, the presence of bile increases absorption of lead from the gastrointestinal tract because lead forms a complex with some bile components, most probably proteins. Therefore, the effect of dietary fat on lead absorption may be due to the stimulation of bile flow during fat digestion, which contributes to lead absorption.

Our study found a significant positive association between total caloric intake and BPb. Some studies have reported a negative association between BPb and calories; an explanation for the finding has been that lead is less readily absorbed when food is present in the stomach.[7,8] However, a positive association has an equally plausible explanation. The contamination of food with lead can occur from the soil or air or even through packaging.[22] Thus the more food that is consumed, the greater the chance that lead is consumed. This latter explanation would lead to a positive association between lead and both fat and total calories. One should not dismiss the possibility that caloric intake at both high and low extremes could influence the absorption of lead.

In our study proteins and carbohydrates were not found to be significantly associated with BPb level after controlling for other nutrients, exposures, and demographics. Studies that have found proteins or carbohydrates to be associated with levels of BPb have not controlled for other key nutritional components. Yet our analyses demonstrated that they confound these relationships. The differences in analyses may, in fact, explain some of the inconsistency within the literature.[9–13] We believe that the relationships for proteins and carbohydrates with BPb were likely to be more accurately described when other key nutritional components were controlled as was performed in the analyses reported here.

A few limitations of this study should be noted. First, observational epidemiologic studies, in general, cannot establish causality. Second, findings cannot be generalized to the entire population of children in the United States because the subjects in the current study were predominantly black, came from low-income families, and lived in old housing in an urban community. At the same time, the findings can be generalized to a population of high-risk children who probably have the most to gain from an understanding of the role of nutritional factors and possibly the development of nutritional interventions. Finally, we cannot report the absolute amount of fat intake, for example, that relates to increases in BPb level nor compare the children's diets with recommended daily allowances of fats, proteins, and carbohydrates. The food frequency questionnaire with the computation of nutrient intake (eg, in grams) used here was developed for adults and has not been modified for children. However, the nutrient intake values do indicate relative intake levels and, therefore, are appropriate for examining whether associations exist with selected nutrients, and if so, the directions of the associations.

A significant component that may contribute to increased BPb levels in inner-city children is nutritional status, specifically dietary fat and total caloric intake. A main priority in eliminating the problem of high BPb in children is removal of environmental lead exposures. Because this is not always a feasible and timely solution, the findings reported here suggest a potential means of secondary intervention. The significant associations of total calories and dietary fat with BPb, independent of other key nutrients, are important findings that, if replicated, would further strengthen the recommendation of a low-fat diet as a healthy one for children. Not only would such a diet be expected to lead to reduction in cardiovascular risk, but may also lead to different methods of treatment and prevention of lead poisoning in children.

Further investigations, particularly regarding the relationship between dietary fat and BPb level, are warranted to see if similar results are obtained. More precise nutritional measurements would assist in estimating the specific amounts of dietary fat that relate to a given increase in BPb levels.

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COLLATERAL DAMAGE

As the welfare-reform debate begins to boil, the place to begin is with an elemental fact: no child in America asked to be here.

Each was summoned into existence by the acts of adults. And no child is going to be spiritually improved by being collateral damage in a bombardment of severities targeted at adults who may or may not deserve more severe treatment from the welfare system.

Phil Gramm says welfare recipients are people "in the wagon" who ought to get out and "help the rest of us pull." Well. Of the 14 million people receiving Aid to Families with Dependent Children, 9 million are children. Even if we get all these free-riders into wee harnesses, the wagon will not move much faster.

Will GF. *Baltimore Sun*. September 14, 1995.

Noted by Alain Joffe, MD