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Association of Erythrocyte Protoporphyrin with Blood Lead Level and Iron Status in the Second National Health and Nutrition Examination Survey, 1976–1980[1]

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Both iron status and body burden of lead influence heme biosynthesis. Measurement of protoporphyrin IX in the circulating erythrocyte (EP) has been used to index the extent of lead exposure and iron deficiency. The association of iron status and blood lead level with the level of EP in whole blood for persons ages 6 months through 74 years in the general U.S. population has been investigated by using data obtained in the second National Health and Nutrition Examination Survey (NHANES II). Iron status was defined as a function of percentage transferrin saturation (%TS) and total iron-binding capacity (TIBC). Both low iron status (%TS $\leq$16.0 or TIBC $\geq$450 μg/dl serum) and elevated blood lead levels ($\geq$30 μg/dl) were associated with increased EP concentrations. The analysis of the proportions of persons in the U.S. population with EP levels above the 95th percentile (30 μg EP/dl of whole blood in the NHANES II data) support the concern that iron status has considerable influence on interpretation of EP levels recommended for use in screening programs aimed at identifying children with lead toxicity. With screening techniques based on EP only, currently used in various public health programs, a considerable number of children with blood lead levels of $\geq$30 and $\leq$50 μg/dl are not referred for further diagnostic evaluation.

INTRODUCTION

Lead toxicity, recognized as a public health problem since antiquity (Nriagu, 1983), includes young children and workers with occupational lead exposure (Lin-Fu, 1972; Mahaffey *et al.*, 1982) among its highest risk groups. National estimates of blood lead levels in the U.S. population indicate that large numbers of young children have elevated blood lead concentrations, e.g., $\geq$30 μg/dl of whole blood (μg/dl WB) (Mahaffey *et al.*, 1982). Although decreasing environmental lead pollution has been reflected by a decline in blood lead levels (Annest *et al.*, 1983) screening programs to detect persons with excess lead exposure remain an important public health activity.

During the last decade, the measurement of erythrocyte protoporphyrin (EP) in

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TABLE 1
NUMBER AND PERCENTAGE OF EXAMINEES AGES 6 MONTHS TO 5 YEARS BY SELECTED BLOOD LEAD[a] AND ERYTHROCYTE PROTOPORPHYRIN[a] LEVELS: NHANES II, 1976–1980

Blood lead level (μg/dl WB)[b]	Erythrocyte protoporphyrin level (μg/dl WB)[c]							
	Less than 30		30–49		50 or more		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Less than 20	1596	91.4	137	7.9	13	0.7	1746	73.9
20–29	421	84.2	63	12.6	16	3.2	500	21.1
30–49	56	50.5	36	32.4	19	17.1	111	4.7
50–76	0	0.0	2	28.6	5	71.4	7	0.3
Total	2073	87.7	238	10.1	53	2.2	2364	100.0

[a] Determined from blood specimens drawn by venipuncture.
[b] To convert blood lead values to micromoles per liter multiply by 0.04826.
[c] To convert erythrocyte protoporphyrin values to micromoles per liter multiply by 0.01778.

the blood has been increasingly used in screening young children for lead toxicity and for iron deficiency (Centers for Disease Control, 1978) as well as monitoring occupational lead exposure in adults. Among groups exposed to elevated levels of lead but who are infrequently iron deficient (e.g., adult males occupationally exposed to lead) elevated EP levels are a function of lead exposure[3] (World Health Organization, 1980). However, in population groups where both iron deficiency and elevated blood lead levels are relatively prevalent, e.g., young children from low-income households (Mahaffey *et al.*, 1982; Singer *et al.*, 1982) the use of EP tests for lead screening can be complicated by the influence of iron status on EP level. Yip and Dallman (1984) reported that age/sex differences in EP values diminished markedly when the influence of lead toxicity and iron status were excluded.

A previously published analysis of the National Health and Nutrition Examination Survey (NHANES II) data on EP and blood lead levels for children ages 6 months through 5 years (Table 1) indicated that a substantial portion of young children with elevated blood lead ($\geq$30 μg/dl WB) had EP levels $<$30 μg/dl whole blood (Annest and Mahaffey, 1984). These analyses suggested that the influence of iron status on EP concentration should be evaluated using data from NHANES II.

In this paper we report the association of blood lead and iron status with EP levels for U.S. population ages 6 months through 74 years based on findings for the nationally representative sample of the general population examined in the second survey (NHANES II). Iron status is defined as a function of percentage transferrin saturation (%TS) and total iron-binding capacity (TIBC). The relevance of these findings to the identification of persons with lead toxicity is discussed.

[3] There is a rare genetic disorder, erythropoietic protoporphyria, that is characterized by very high concentrations of erythrocyte protoporphyrin (Piomelli *et al.*, 1975; Lamola *et al.*, 1975). However, this disease is accompanied by pronounced cutaneous photosensitivity (Mathews-Roth, 1977).

METHODOLOGY

Survey sample design. The NHANES II was a cross-sectional study conducted from February 1976 through February 1980, which used a sample of 27,801 persons selected from 64 areas in the United States (McDowell *et al.*, 1981). National estimates obtained by using data from these 64 areas are representative of the U.S. civilian noninstitutionalized population ages 6 months through 74 years. The survey program was set up to obtain health and nutritional data through standardized examinations, tests, measurements, medical history, and dietary questionnaires. Numerous laboratory assessments from blood and urine specimens were included (McDowell *et al.*, 1981). Biochemical determinations from blood specimens used in this report are blood lead, total iron-binding capacity, serum iron, and erythrocyte protoporphyrin IX (as EP). Further details of the complex survey design and collection of the blood lead samples are given elsewhere (Mahaffey *et al.*, 1979, 1982; Annest *et al.*, 1982; Gunter *et al.*, 1981). Tests of significant differences between means were conducted using a regression program that accounted for the complex survey design (Holt, 1981).

Laboratory assessments. Erythrocyte protoporphyrin levels were measured for all examinees as free erythrocyte protoporphyrin IX by using a modification (Gunter *et al.*, 1981) of the extraction method described (Sassa *et al.*, 1973).

Protoporphyrin IX was extracted from EDTA and then back-extracted into dilute hydrochloric acid; details of the procedure are described elsewhere (Gunter *et al.*, 1981). The protoporphyrin concentrations were measured fluorimetrically and the results are expressed as micrograms of free protoporphyrin IX per deciliter of whole blood.

Serum iron and TIBC were measured for all examinees by a modified automated Technicon AAII-25 technique based on quantitation of serum iron with ferrozine in pH 4.7 acetate buffer (Ramsey, 1957; Giovanniello *et al.*, 1968). In the determination of TIBC, the serum was mixed with excess iron (one part serum to two parts 400 μg/dl solution of iron) to permit complete saturation of iron-binding sites on the serum transferrin molecule. The percentage transferrin saturation (%TS) was calculated by

$$\%TS = (\text{serum iron}/TIBC) \times 100.$$

Lead concentrations from venous blood specimens were measured using a modification of the microcup atomic absorption method (Barthel *et al.*, 1973) with deuterium background correction. Details of the method and quality-control systems are reported elsewhere (Mahaffey *et al.*, 1982). Two quality-control systems were employed for blood lead analyses throughout the survey; "bench" quality-control samples were inserted by the analyst and measured in duplicate with each analytic run to allow the analyst to make judgments on the day of analysis, and "blind" quality-control samples were placed in vials, labeled with false patient-identification numbers, and processed so that they were indistinguishable from regular NHANES II samples. At least one blind sample was incorporated with every 20 NHANES II samples and analyzed in duplicate.

The ranges of the bench quality-control coefficients of variation for all exam-

inees are summarized as follows: EP less than 76 μg/dl WB, 10.0 to 15.5%; EP between 76 and 92 μg/dl WB, 9.9 to 10.6%; EP between 136 and 199 μg/dl WB, 6.4 to 8.0%; serum iron, 1.5 to 2.1%; TIBC, 1.9 to 2.8%; and blood lead, 7.0 to 15.0%.

Description of the data. Means and standard errors of the four biochemical measures are presented in Table 2 for each of the five selected age groups. These estimates are similar to those presented elsewhere as national estimates of blood lead levels (Mahaffey *et al.*, 1982), EP (Fulwood *et al.*, 1982), and %TS (Fulwood *et al.*, 1982). For children and youths ages 6 months through 17 years, mean blood lead levels decreased and mean %TS increased with increasing age; mean EP and mean TIBC were significantly higher in the youngest age group (6 months through 2 years) than in the other two groups ($P \leq 0.05$). For adults ages 18 through 74 years, mean blood lead levels and mean %TS were significantly higher for men than women ($P \leq 0.05$); mean EP values were similar for both sexes, and mean TIBC was significantly higher for women than men ($P \leq 0.05$). These relationships were similar for blacks and whites.

Limitations of the data. There are limitations on the use of these NHANES II data because of the potential for bias associated with missing data. Blood specimens for assessment of lead concentrations were not obtained on 39% of the 16,563 persons in the lead subsample, usually because of nonresponse at various stages of the survey. A detailed description of the investigation of sample persons with blood lead data is presented elsewhere (Annest *et al.*, 1982). The results suggested no evidence of bias in that nonresponse was distributed uniformly by race, sex, degree of urbanization (place of residence), and annual family income. However, the total nonresponse in the lead subsample was greater for young children ages 6 months through 5 years (51.0%) than for those ages 6 through 17 years (28.6%) or ages 18 through 74 years (35.7%).

TABLE 2

MEANS AND STANDARD ERRORS FOR VARIABLES USED FOR ANALYSIS, BY AGE: UNITED STATES, 1976–1980

Selected age group	Blood lead level[a] μg/dl WB[d]	Erythrocyte protoporphyrin[b] μg/dl WB	Transferrin saturation Percentage	Total iron-binding capacity[c] μg/dl serum
All ages	14.0 ± 0.25[e]	21.7 ± 0.21	27.0 ± 0.23	375.3 ± 2.04
6 Months–2 years	16.3 ± 0.58	25.1 ± 0.50	19.6 ± 0.59	410.7 ± 5.09
3–5 Years	15.9 ± 0.40	21.6 ± 0.36	23.0 ± 0.29	381.4 ± 2.03
6–17 Years	12.5 ± 0.30	20.7 ± 0.29	25.1 ± 0.35	390.3 ± 2.46
Men, 18–74 years	16.9 ± 0.29	21.6 ± 0.28	29.5 ± 0.28	362.6 ± 2.02
Women, 18–74 years	11.8 ± 0.22	22.3 ± 0.24	26.4 ± 0.33	377.2 ± 2.42

[a] To convert blood lead values to micromoles per liter multiply by 0.04826.

[b] To convert erythrocyte protoporphyrin values to micromoles per liter multiply by 0.01778.

[c] To convert iron-binding capacity values to micromoles per liter multiply by 0.1791.

[d] Whole blood.

[e] Mean ± standard error of the mean, national estimates (weighted data).

Of the persons in the lead subsample with venous blood lead values, 0.6% were missing EP values and 15.2% were missing both %TS and TIBC values. The percentage of persons with missing %TS and TIBC values was dependent upon age, with nonresponse least among adults and most among young children. However, since nonresponse among NHANES II sample persons was apparently independent of their perceived health and nutritional status (Forthofer, 1983), the results of an analysis of the interrelationships between EP, blood lead level, and iron status would not be expected to be affected significantly by the degree and distribution of missing data.

Statistical methods. A logit analysis was used to model the log of the odds of having elevated EP levels versus nonelevated EP levels. An EP of 30 μg/dl WB was used to define elevated EP values in the logit analysis. An EP value of 30 is the 95th percentile of the weighted NHANES II EP data. Categorical data analysis was used to estimate the odds for population subgroups defined by blood lead level and iron status (Table 3). This method was used because of interest in individuals having low iron status and elevated blood lead levels. Preliminary analysis of the continuous data indicated that these effects were obscured by the large number of individuals with nonelevated blood lead and normal iron status. The logit analysis (Forthofer and Lehnen, 1981) incorporated the sample weights and the complex survey design (McDowell *et al.*, 1981; Holt, 1981; Landis *et al.*, 1976). The complete model was $\ln(pij/1 - pij) = B_0 + B_1(X_1) + B_2(X_2) + B_3(X_3) + B_4(X_1X_2) + B_5(X_1X_3) + eij$ where pij is the proportion of examinees with EP ≥30 μg/dl WB in the ith iron by jth blood lead status category. (An EP of 30 μg/dl WB was used to define elevated EP values in the logit analysis. An EP value of 30 is the 95th percentile of the weighted NHANES II EP data.) Iron status, represented by X_1, was coded as 1 and 0 for the low (%TS ≤16.0 or TIBC ≥450 μg/dl) and normal %TS ≥16.0 and TIBC ≤450 μg/dl), respectively, to test the differen-

TABLE 3
THE ODDS OF HAVING AN ELEVATED EP (30 μg/dl WHOLE BLOOD OR MORE) VERSUS A NORMAL EP, BY IRON AND BLOOD LEAD STATUS: UNITED STATES, 1976–1980

Iron status	Blood lead status	Odds ratio[a] Elevated EP:nonelevated EP
Low[b]	High[d]	1.3:1.0
Low	Medium[e]	1.0:5.3
Low	Low[f]	1.0:7.1
Normal[c]	High	1.0:5.1
Normal	Medium	1.0:22.0
Normal	Low	1.0:18.8

[a] Predicted from the logit analysis of the national estimates (weighted data).
[b] %TS ≤ 16.0 or TIBC ≥ 450.
[c] %TS > 16.0 and TIBC < 450.
[d] PbB ≥ 30 μg/dl.
[e] 20 ≤ PbB < 30 μg/dl.
[f] PbB < 20 μg/dl.

tial effects of iron status. Blood lead status, represented by X_2 and X_3, was coded as (1,0), (0,1), and (0,0) for the higher (≥30 μg/dl WB), medium (20–29 μg/dl WB), and low (<20 μg/dl WB) categories, respectively, to test the differential effects of blood lead level. The terms associated with B_3 and B_5 were eliminated from the model since neither of the parameter estimates was significantly different from zero ($P \geq 0.85$).

There was a good fit of the reduced model (χ^2 due to error = 1.95, $df = 2$, $P = 0.38$). Using this model, the following tests of the hypothesis were conducted: *no* interaction between iron and lead status (H_0: $B_4 = 0$), *no* independent effect of iron status (H_0: $B_1 = 0$), and *no* independent effect of lead status (H_0: $B_2 = 0$). The latter hypothesis tests the independent effect of blood lead level associated with differences between the low and medium lead groups versus the high lead group.

RESULTS

The results of the statistical analysis indicated a strong association between elevated blood lead concentration and low iron status in relation to EP level. The percentage of persons with EP values of 30.0 μg/dl WB or more by iron and blood lead status computed from the NHANES II data are given in Fig. 1. In general, the percentage of persons with elevated EP is highest among those with low iron status and high blood lead status.

The odds of having an elevated EP were influenced by iron status, blood lead level, and the combination of these (Table 3). For example, the odds of having an elevated EP depend upon the independent effects and interaction between blood lead and iron status. As shown in Table 3, persons with both low iron status and high blood lead levels are approximately six and one-half times more likely to have elevated EPs than those with normal iron status and high blood lead levels, while persons with low iron status and low blood lead levels are approximately two and one-half times more likely to have elevated EPs than those with normal iron status and low blood lead levels.

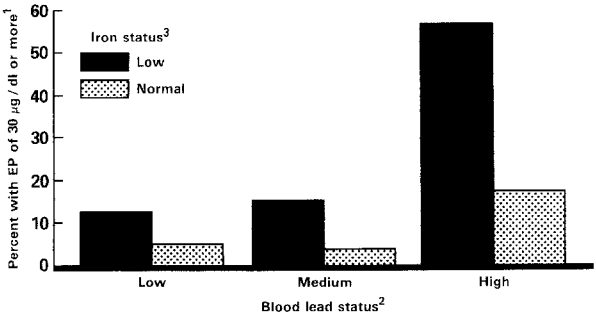

FIG. 1. Percentage of persons ages 6 months–74 years with erythrocyte protoporphyrin (EP) values of 30.0 μg/dl WB or more by blood lead level (PbB) and iron status: United States, 1976–1980. [1]Computed using weighted data from NHANES II examinees ages 6 months–74 years. [2]Low, PbB <20 μg/dl; medium, 20 ≤ PbB < 30 μg/dl; high, PbB ≥30 μg/dl. [3]Low, %TS ≤16.0 or TIBC ≥450 μg/dl; normal, %TS >16.0 and TIBC <450 μg/dl.

Tests of hypotheses from the logit analysis indicated that there is a statistically significant interaction between blood lead level and iron status, and either blood lead level or iron status can independently influence the likelihood of having an elevated EP. The hypothesis of $B_4 = 0$ (that is no interaction between iron status and blood lead on EP) was rejected at the 0.07 level, $\chi^2(df = 1) = 3.37$. The hypothesis of $B_1 = 0$ (no independent iron effect) and $B_2 = 0$ (no independent lead effect) were rejected at the 0.001 level with $\chi^2(df = 1) = 70.91$ and 21.39, respectively. The influence of iron status and blood lead level on the cumulative distribution of EP is shown in Figure 2.

Ideally, it would have been desirable to test the association between EP, iron status and blood lead level for each group of people having a different prevalence of iron deficiency and excess lead exposure. However, because of limitations of sample size (46 examinees ages 6 months–74 years) in the high lead-low iron status group, similar analyses and test of hypotheses were not conducted for subgroups of the NHANES II examinees based on subpopulations grouped by age, race, etc. Smaller sample sizes would have presented a problem with unstable estimates of sampling variance. Although the degree of the associations of iron status, blood lead level and EP may vary among population subgroups, the overall trend in the percentage of persons with elevated EPs by blood lead level and iron status was observed to be consistent for each of the selected age groups in Table 2, for both sexes and for blacks and whites.

The present analysis of national estimates based on NHANES II data indicated that, for the general population ages 6 months through 74 years, reduced iron status and excess lead exposure are interactively associated with increased levels of EP.

Based on the weighted proportions of persons examined in NHANES II who had substantially elevated EP levels (2 standard deviations above the geometric mean, or ≥30 μg EP/dl WB), the independent and combined effects of lead exposure (as measured by blood lead level) and low iron status have been clearly demonstrated.

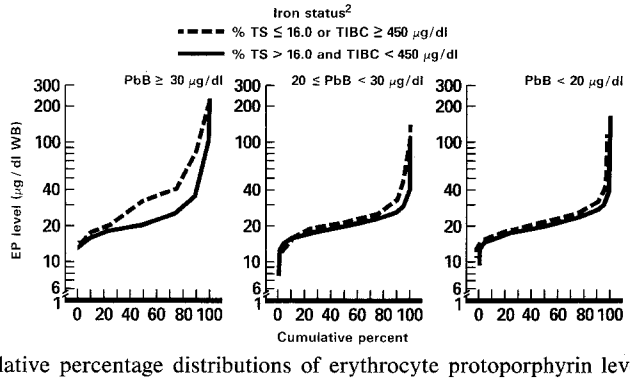

FIG. 2. Cumulative percentage distributions of erythrocyte protoporphyrin levels (EP) by blood lead level (PbB) and iron status: United States, 1976–1980. Plotted on a semilogarithmic scale. Distributions computed using weighted data from NHANES II examinees ages 6 months–74 years. [2]%TS, percentage transferrin saturation; TIBC, total iron-binding capacity.

DISCUSSION

The exponential increase in the weighted proportion of persons with elevated EP associated with high blood lead levels and low iron status demonstrates the greater vulnerability of iron-deficient individuals to the effects of lead. A number of studies suggest a metabolic basis for this association. Iron-deficient animals (Mahaffey-Six and Goyer, 1972; Ragan, 1977) and iron-deficient humans (Watson *et al.*, 1980) absorb a greater percentage of ingested lead from the gastrointestinal tract. Iron-deficient rats had significantly higher blood and tissue lead levels than did rats exposed to similar amounts of lead but receiving an iron-adequate diet (Mahaffey-Six and Goyer, 1972).

Lead interferes with heme biosynthesis through disturbance of the activity of three major enzymes: δ-aminolevulinic acid synthetase, δ-aminolevulinic acid dehydratase, and ferrochelatase (Moore *et al.*, 1980). In humans the rate-limiting enzyme influenced by lead is δ-aminolevulinic acid synthetase (Moore and Goldberg, 1985). Iron deficiency impairs mitochondrial heme synthesis, which depends upon an adequate supply of Fe(II) to the mitochondrial enzyme ferrochelatase (Flatmark and Romslo, 1975). Activity of ferrochelatase relies on energy production by tightly coupled mitochondria (Koller and Romslo, 1977). When insufficient iron substrate, as Fe(II), is available in the mitochondria for incorporation by ferrochelatase into heme, EP levels increase. Lead is known to interfere with mitochondrial energy metabolism (Goyer and Rhyne, 1973; Fowler *et al.*, 1980; Holtzman *et al.*, 1978; Bull *et al.*, 1979) which is necessary to reduce Fe(III) to Fe(II) before insertion into the porphyrin ring. Sassa *et al.* (1973), in a review of the effects of lead on heme metabolism, indicated that lead interferes with iron utilization for heme formation in the mitochondria, producing excessive accumulation of iron and destruction of the mitochondria. Kapoor *et al.* (1984) have reported that the enzyme kinetics of ferrochelatase in isolated human reticulocytes change with both iron and lead concentration. When iron deficiency is present ferrochelatase is more sensitive to lead effects. The cellular basis for greater susceptibility of iron-deficient animals to lead is that limited iron in the mitochondria apparently enhances the impairment by lead of iron utilization for heme synthesis.

Use of EP in Screening Programs and Epidemiologic Surveys

Screening for lead toxicity has been done traditionally by measurement of blood lead concentration. However, because of the analytical difficulties and the potential for contamination of blood samples, especially micro samples obtained by finger puncture (Crisler *et al.*, 1973), a combination of blood lead measurement and EP determination would be more accurate and effective in identifying children at greatest risk of lead toxicity and/or iron deficiency. The screening criteria recommended by the Centers for Disease Control (1978) were defined to allow screening of large numbers of children in times of limited financial resources. They were based on the premise that accumulation of EP in the blood was indicative of some of the earliest metabolic derangements associated with lead exposure. The results presented in this manuscript indicate that, after ac-

counting for iron status, EP levels of 30 μg/dl or more are significantly ($P \leq 0.001$) more prevalent for children ages 6 months through 5 years with blood lead levels of 20–29 μg/dl than for those with lower blood lead levels (≤20 μg/dl).

In many pediatric lead screening programs, EP is measured first and the child referred for medical evaluation if the EP values exceed certain limits, usually those recommended by the Centers for Disease Control (1978, 1985). Based on the data from NHANES II for children ages 6 months through 5 years (Table 1) using the 1978 criteria of EP ≥50 μg/dl as the basis limit for referral for medical evaluation; 53 children had an EP ≥50 with 24 (45%) of these 53 children having a blood lead ≥30 μg/dl. Looking at these data from another perspective among the 118 children having a blood lead ≥30 μg/dl, only 24 (20.3%) had an EP value ≥50 μg/dl. This means that if the EP value is the only basis for recommending followup, approximately 80% of the 118 children would not be referred.

If 30 μg EP/100 dl whole blood is used as the limit value for referring children for further evaluation, of the 118 children having a blood lead ≥30 μg/dl, 62 (53%) had an EP value ≥30 μg EP/dl whole blood. If the EP value is the only basis for referring a child for additional evaluation, only about one-half of the children having a blood lead ≥30 μg/dl would be detected based on the data from NHANES II. Currently lead toxicity is defined as an elevated blood lead level (25 μg/dl or greater) with an EP level of 35 μg/dl or greater (Centers for Disease Control, 1985).

The association of blood lead level and iron status with EP level in the NHANES II data indicates that both conditions need be considered when interpreting results of EP tests used in many childhood lead screening programs. The purpose in presenting these data is to provide state and local programs with information on the influence of iron status on EP levels. In many public health programs, including many of the Lead Poisoning Prevention Programs, children are initially screened by measuring EP levels. Subsequently, blood specimens for lead determinations are collected only from those children with elevated EP levels. As noted above, this procedure could result in a substantial number of children with blood lead levels in the range of 30–49 μg/dl WB not being referred for further diagnostic evaluation.

Public Health Implications of These Data

Although lead-induced impairment of heme biosynthesis is commonly measured in the erythrocyte as the accumulation of protoporphyrin, reduced heme biosynthesis has physiological significance for all tissues (Piomelli *et al.*, 1982). The buildup of protoporphyrin levels in the blood takes time; therefore, measurement of EP potentially provides a better indicator of long-term lead exposure than blood lead level. Cavalleri *et al.* (1981) reported that graded increases in EP values were evident at blood lead levels between 10 and 20 μg/dl WB, indicating that the "no-response" level for EP accumulation in preschool- and primary school-aged children was lower than 10 μg/dl WB. Piomelli *et al.* (1982) found an exponential increase in EP with increasing blood lead level with an apparent threshold effect at a blood lead between 15 and 18 μg/dl WB for children ages 2 through 12 years from a sample selected to minimize the number of iron-deficient subjects.

Blood lead levels in the range of 25–49 μg/dl are quite prevalent among children in low-income households (Mahaffey *et al.*, 1982), a group in which low iron status is also common (Dallman *et al.*, 1984; Fulwood *et al.*, 1982). In light of these considerations, community screening programs seeking to identify children with excess body burden of lead or iron deficiency or both may find these data helpful in assessing how to apply federal guidelines on prevention of pediatric lead toxicity. As observed in these NHANES II data, a high percentage of children having a blood lead concentration ≥30 μg/dl did not have an EP value ≥50 μg/dl. The high percentage of false negatives for lead exposure may be due to better nutritional status among the general population compared with the high-risk groups targeted by screening programs.

Increased understanding of the range of health effects associated with lead exposure (Needleman, 1980; National Research Council, 1980) has resulted in a need to refer children for diagnostic evaluation at progressively lower blood lead levels. The basis for this need is the effects of low-level lead exposures on intellectual and behavioral development among young children. These effects may occur in children at levels of blood lead lower than can be reliably identified using EP as the primary screening mechanism. As lower levels of blood lead become of interest, the utility of EP as a screening technique declines. In this sample of the 1746 children having a blood lead <20 μg/dl, 150 (8.6%) had an EP level ≥30 μg/dl. Currently, lead toxicity is defined as an elevated blood lead level (≥25 μg/dl) with an EP of 35 μg/dl or greater (Centers for Disease Control, 1985). Screening programs using EP only need be aware of the importance of determining blood lead as well as EP if feasible.

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