

Parathyroid Hormone Status Does Not Influence Blood and Bone Lead Levels in Dialysis Patients

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ABSTRACT: Elevated blood lead levels, a risk factor for cardiovascular disease, have been reported among patients with end-stage renal disease. We evaluated whether these higher levels are due to release of lead from the skeleton because of uremic bone disease. Fifty-one African-American patients with end-stage renal disease were recruited from 3 Tulane University dialysis programs between January and July 2005. An interviewer-administered questionnaire, blood specimen collection and ^{109}Cd -based x-ray fluorescence measurement of tibia lead occurred during a single study visit. Levels of serum parathyroid hormone (PTH), calcium, phosphorus, and albumin were abstracted from the patients' charts. The distributions of tibia and blood lead were similar across levels of serum PTH. Specifically, for participants with serum PTH <300 pg/mL and ≥ 300 pg/mL, median tibia lead

was 21 $\mu\text{g/g}$ and 17 $\mu\text{g/g}$, respectively, and geometric mean blood lead levels were 6.7 $\mu\text{g/dL}$ and 6.6 $\mu\text{g/dL}$, respectively ($P = 0.70$ and 0.87 , respectively). After adjustment for age, gender, education, cigarette smoking, and dialysis vintage, natural log transformed blood lead was 0.022 lower in patients with serum PTH ≥ 300 pg/mL ($P = 0.87$). There were no differences in tibia and blood lead across levels of serum calcium, serum phosphorus, and the calcium phosphorus product (all $P > 0.40$). The high blood lead levels observed among dialysis patients do not appear to be the result of increased bone turnover. The causes of higher blood lead levels for these patients need to be identified and attenuated. **KEY INDEXING TERMS:** End-stage kidney disease; Dialysis; Bone lead; Uremic bone disease; X-ray fluorescence. [*Am J Med Sci* 2007;334(6):415–420.]

Despite a continued decline over the past 2 decades, blood lead levels in the U.S. population remain directly associated with increased risk for hypertension, kidney disease, and cardiovascular mortality.^{1–4} Kidney injury resulting from lead toxicity can progress to chronic kidney disease and end-stage renal disease (ESRD). Thus, lead exposure represents a potentially reversible cause of kidney disease.^{5–8}

The association between lead exposure and kidney injury has been based, generally, on investigations in populations with modest to moderate renal insufficiency and there are only few studies involving end-stage kidney disease patients.^{5,8–11} However,

the value of lead measurements in patients with kidney disease has been questioned. The specific concerns are whether elevated lead levels might be secondary to renal insufficiency and whether the alterations in bone metabolism associated with renal disease result in release to circulation of lead sequestered in bone. Such mechanisms might confound the association of blood lead with kidney disease.

It is generally agreed that renal disease, especially mild-to-moderate renal insufficiency per se does not cause retention of lead^{6,12} and that kidney patients without unusual high exposure to lead do not have increased bone lead.^{13,14} Bone metabolic derangements, and calcium, phosphorus, and parathyroid hormone (PTH) abnormalities are more pronounced and more common in dialysis patients, yet the relation between these changes and blood and bone lead levels has not been systematically evaluated previously. Thus, it remains unclear whether increased parathyroid hormone (PTH) and changes in bone metabolism associated with advanced kidney disease influence lead measurements. In this study, we evaluated the relationship between PTH and whole blood lead levels, and tibia lead levels estimated by x-ray fluorescence to determine whether secondary hyperparathyroidism of uremia influences blood and tibia lead levels in patients with ESRD.

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Submitted February 15, 2007; accepted in revised form March 28, 2007.

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Methods

Study Population

Cases of ESRD receiving chronic maintenance hemodialysis treatment were recruited from 3 Tulane University–affiliated dialysis clinics between January and July 2005. The hemodialysis patient population at Tulane-affiliated dialysis clinics was overwhelmingly African-American. Therefore, the current study was limited to African-Americans. During the recruitment process, potential participants were asked if they had ever been told by a physician or other healthcare provider that they had lead poisoning. Those reporting a previous history were excluded from the current study. All women who were pre-menopausal (ie, those reporting a menstrual cycle within the previous 12 months) received a pregnancy test due to the use of radiation in measuring tibia lead. No women were pregnant. Overall, 55 participants met the eligibility criteria and completed the study visit. Of these, 51 had data available for chart abstraction, and were therefore included in the current analyses.

Data Collection

Data collection occurred during a single study visit to the Tulane University Office of Health Research and through medical chart abstraction. Procedures performed during the study visit included participant interviews, assessment of height and weight, a blood specimen collection, and tibia lead measurement. All study procedures were performed by trained study staff following a standardized protocol. Questionnaires were interviewer-administered and used to ascertain demographics, education, cigarette smoking, and alcohol consumption. Height was measured with a stadiometer while participants stood erect and weight was measured with an electronic digital scale while the participant was wearing light clothes. Body mass index was calculated as weight in kilograms divided by height in meters squared.

Measurement of Tibia Lead

Tibia lead was assessed via a 30-minute measurement of the left mid-tibia diaphysis. The system used ¹⁰⁹Cd as the fluorescence source in a backscatter geometry, configured with the sample, to fluoresce the K shell x-rays of lead. The lead x-rays

were recorded with an intrinsic germanium detector (Canberra GL2020R, Meriden CT), quantified, and compared with calibration data to estimate the concentration of bone lead present.^{15–20} Because emitted x-rays are attenuated as they pass through bone and overlying tissues, the recorded lead K-shell x-rays are normalized to the number of ¹⁰⁹Cd γ -rays elastically scattered from the bone itself resulting in a bone lead content measurement that has units of microgram (μ g) of lead per gram (g) of bone mineral.¹⁵ This provides a measurement accuracy that is independent of several important factors such as the distance between the ¹⁰⁹Cd source and the participant, participant positioning, minor movements by subjects, overlying tissue thickness, and bone size, shape, geometry, and mineral density. The method used has been described in full detail elsewhere and validated against chemical measures of lead in bone.²¹ Tibia lead measurements less than zero were recoded as zero.

Measurement of Blood Lead

During the study visit, each participant provided a 14-mL blood specimen. The first 3 mL of blood was collected directly into a certified lead-free Na₂EDTA royal blue top Vacutainer. This tube was kept refrigerated and shipped on the same day to Quest Diagnostics in Metairie, Louisiana, for blood lead measurement. Blood lead levels were determined using graphite furnace atomic absorption spectrophotometry with a detection limit of 3 μ g/dL. Because more than 90% of blood lead is bound in red blood cells, it is undialyzable and is not influenced significantly by hemodialysis.²² Nevertheless, the samples in our population were always collected on an off dialysis day to minimize any possible, even if negligible, effect that hemodialysis treatment may have on blood lead concentration.

PTH, Calcium, and Phosphorus Measurements

Serum PTH, calcium, phosphorus, and albumin levels were abstracted from the patients' medical chart by a trained researcher blinded to the patients' blood and tibia lead levels. The level of each biomarker on the date closest and prior to the study visit was abstracted for each participant. The median time interval between the laboratory measurement and the study visit was 42 days (range, 0 to 90 days) for PTH and 10 days (range, 0 to 37

Table 1. Baseline Characteristics of the Study Patients, Stratified by Parathyroid Hormone, Serum Calcium, Serum Phosphorus, and Calcium Phosphorus Product

	PTH (pg/mL)			Serum Calcium (mg/dL)		
	<300	≥300	P Value	<9	≥9	P Value
Age, y, mean (SE)	50.9 (2.5)	47.9 (2.6)	0.43	47.5 (2.8)	50.7 (2.5)	0.71
Female, %	38.1	63.3	0.08	48.0	57.7	0.49
Completed high school, %	66.7	76.7	0.43	84.0	61.5	0.07
Current smoking, %	42.9	56.7	0.33	52.0	50.0	0.89
Consume alcohol weekly, %	4.8	10.0	0.63	8.0	7.7	1.00
Body mass index, kg/m ² , mean (SE)	27.9 (1.3)	27.5 (1.1)	0.81	29.0 (1.3)	26.4 (0.9)	0.12
Dialysis vintage, y, median	3.8	3.2	0.69	3.8	2.7	0.68
	Serum Phosphorus (mg/dL)			Calcium Phosphorus (mg ² /dL ²)		
	<5.5	≥5.5	P Value	<55	≥55	P Value
Age, y, mean (SE)	49.9 (2.8)	48.2 (2.5)	0.31	49.5 (2.2)	48.1 (3.8)	0.63
Female, %	35.7	73.9	0.007	37.8	92.9	0.004
Completed high school, %	67.9	78.3	0.41	73.0	71.4	1.00
Current smoking, %	50.0	52.2	0.88	51.4	50.0	0.93
Consume alcohol weekly, %	3.6	13.0	0.32	8.1	7.1	1.00
Body mass index, kg/m ² , mean (SE)	28.3 (1.1)	27.0 (1.2)	0.43	28.4 (1.0)	25.8 (1.6)	0.17
Dialysis vintage, y, median	3.2	3.5	0.69	3.1	5.1	0.48

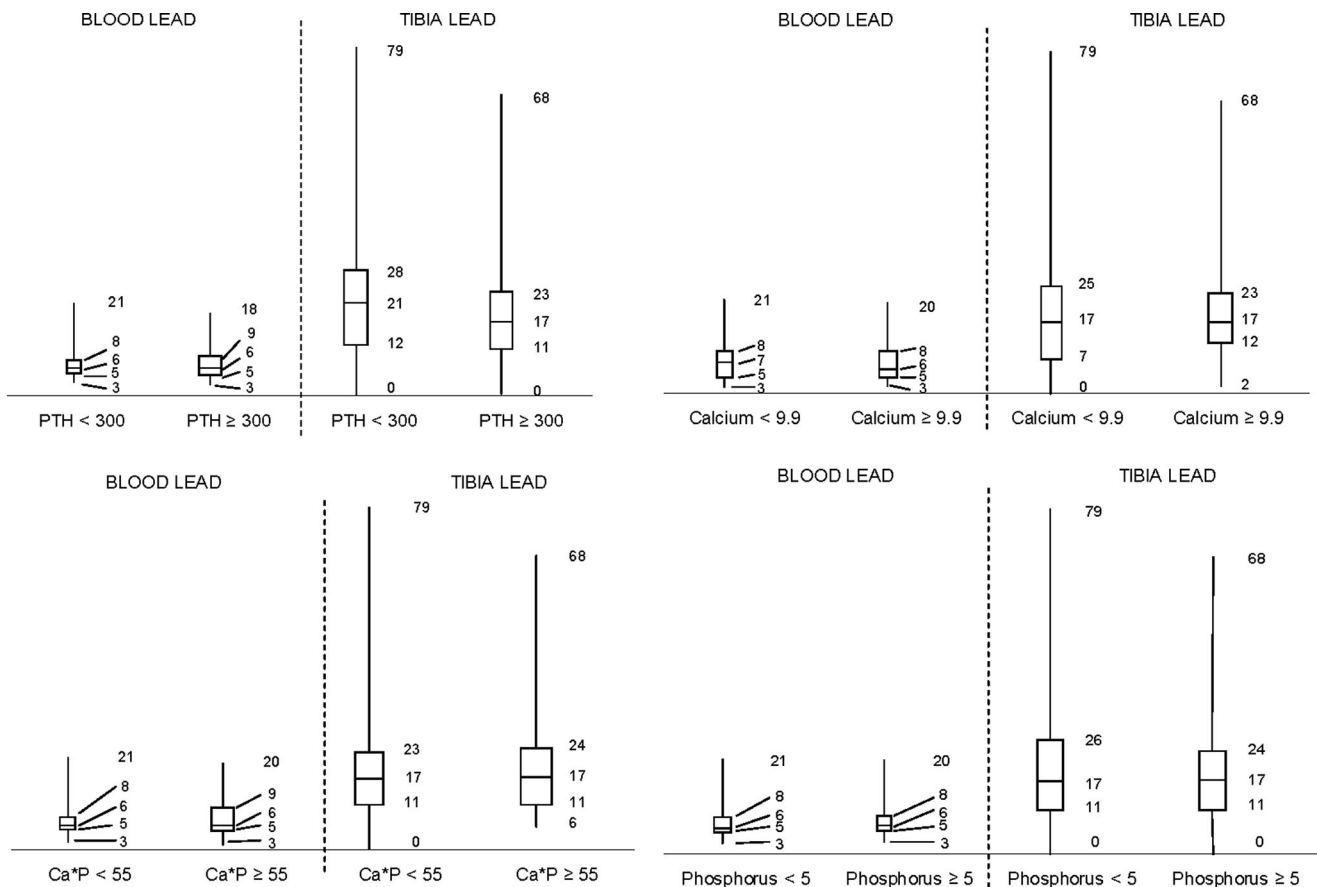


Figure 1. Box plots and blood lead ($\mu\text{g/dL}$) and tibia lead ($\mu\text{g/g}$) by measures of bone turnover.

days) for serum calcium, serum phosphorus, and albumin. Serum calcium was adjusted for albumin by the following formula: adjusted calcium (mg/dL) = calcium (mg/dL) - $((4.0 - \text{albumin (g/dL)}) * 0.8)$.²³ Calcium phosphorus product was calculated as albumin adjusted serum calcium multiplied by serum phosphorus. We dichotomized PTH (<300 pg/mL and ≥ 300 pg/mL), serum calcium (<9 mg/dL and ≥ 9 mg/dL), serum phosphorus (<5.5 mg/dL and ≥ 5.5 mg/dL), and calcium phosphorus product (<55 mg^2/dL^2 and ≥ 55 mg^2/dL^2) based on clinical guidelines recommended by The National Kidney Foundation Kidney Disease Outcomes Quality Initiative (NKF KDOQI).²⁴

All data were double entered into Microsoft Access. The study protocol was approved by the Tulane University Health Sciences Center Institutional Review Board. Written informed consent was obtained from all participants prior to enrollment in the current study.

Statistical Methods

Characteristics of the study population were calculated, as means and proportions, by PTH, serum calcium, serum phosphorus, and calcium phosphorus product levels. Differences in these characteristics across levels were calculated by *t* tests and χ^2 tests for continuous and dichotomous variables, respectively. Box plots of blood and tibia lead, separately, were created by PTH, serum calcium, serum phosphorus, and calcium phosphorus product levels. Next, scatter plots of PTH, serum calcium, serum phosphorus, and calcium phosphorus product, separately, versus blood lead were graphed, and a best-fit regression line was modeled for each pair of variables. Due to its skewed distribution, blood lead was natural log-transformed for the regression model. Geometric mean blood lead levels were calculated by age, sex,

cigarette smoking status, body mass index, dialysis vintage, and levels of PTH, serum calcium, serum phosphorus, and calcium phosphorus product. Finally, the mean difference in natural log-transformed blood lead across covariate levels and PTH, serum calcium, serum phosphorus, and calcium phosphorus product levels was determined using linear regression. Initial regression models included adjustment for age and gender, with subsequent models including additional adjustment for education, smoking status, and dialysis vintage. All data management and analysis was conducted using SAS (version 9.1; SAS Institute, Cary, NC).

Results

Females were more likely than males to have a PTH level ≥ 300 pg/mL , a serum phosphorus level ≥ 5.5 mg/dL , and a calcium phosphorus product level ≥ 55 mg/dL , but the percentage of females and males with serum calcium levels ≥ 9 mg/dL were similar (Table 1). No other significant differences in PTH levels, serum calcium, serum phosphorus, or calcium phosphorus levels were present across covariate levels.

Overall, the geometric mean blood lead level was 6.6 $\mu\text{g/dL}$ and the median tibia lead level was 17 $\mu\text{g/g}$. Box plots showed no significant differences in the distribution of blood and tibia lead when categorized by PTH, serum calcium, serum phosphorus,

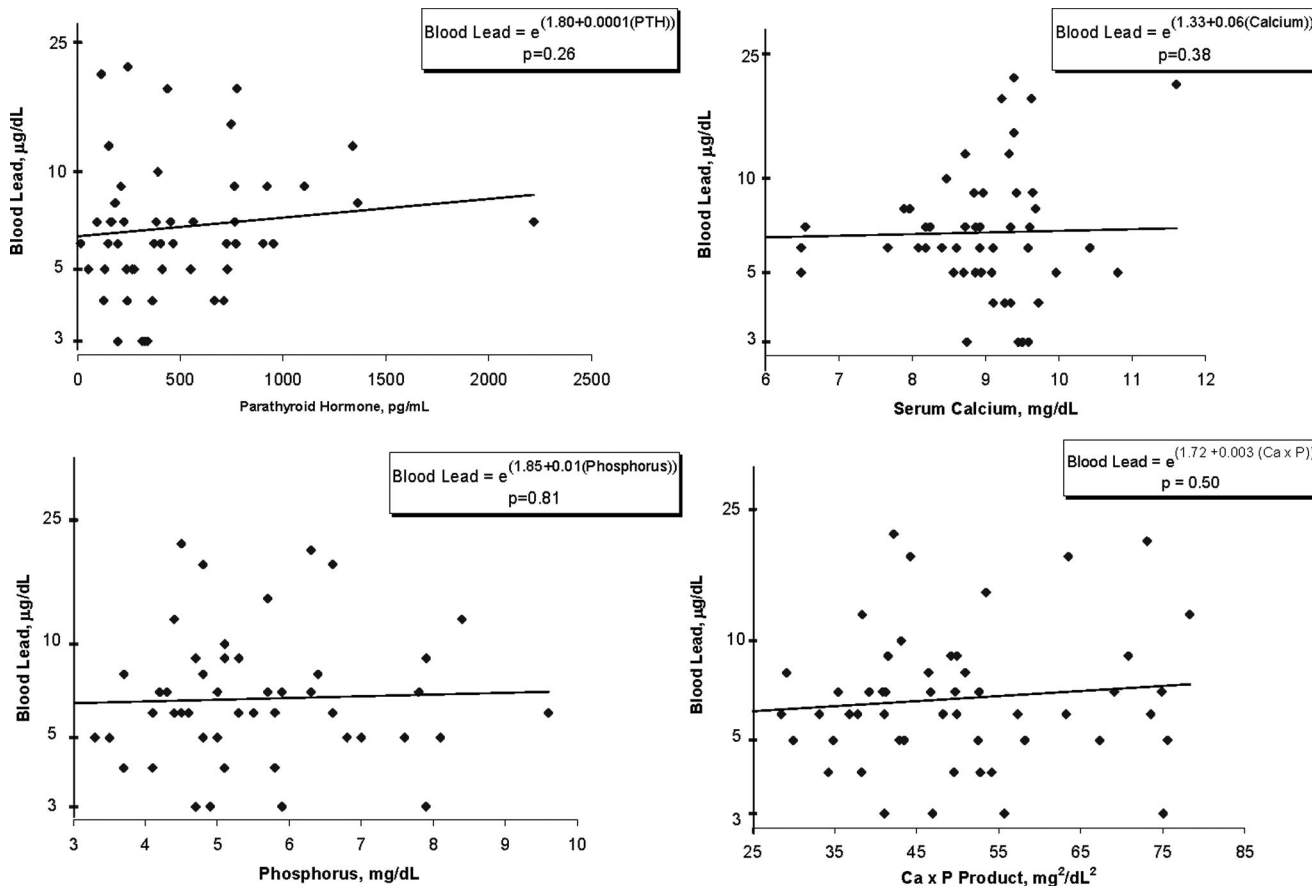


Figure 2. Scatterplots of blood lead (µg/dL) by measures of bone turnover.

and calcium phosphorus product levels (Figure 1). Also, blood lead levels were slightly higher at higher PTH, serum calcium, serum phosphorus, and calcium phosphorus product levels, but these differences were not statistically significant (all $P > 0.25$, Figure 2).

ESRD patients 50 years of age or older had a higher geometric mean blood lead level compared with their counterparts less than 50 years of age. Meanwhile, the geometric mean blood lead level was non-significantly higher in males compared to females, at higher body mass index, among nonsmokers, and persons who had started dialysis within 3.4 years, the median dialysis vintage of study participants, before their study visit (Table 2). Geometric mean blood lead levels were similar across levels of PTH, serum calcium, serum phosphorus, or calcium phosphorus product (all $P > 0.75$). After adjustment for age and gender, PTH, calcium, phosphorus, or calcium phosphorus product were not associated with higher blood lead levels (Table 3). This finding was unaffected by further adjustment for smoking status, education, and dialysis vintage.

Discussion

The key finding in this study is that neither blood lead levels nor tibia lead levels were associated with parameters of high bone turnover in a cohort of 51 hemodialysis patients. Specifically, blood lead concentrations were not higher in patients with PTH values >300 pg/mL, and did not correlate with other parameters of bone metabolism, such as serum calcium, serum phosphorus, or calcium phosphorus product. These data are important as prior reports on the relationship between PTH and blood lead levels have been contradictory.

In a study of 342 bus drivers, Osterloh²⁵ did not find an association between PTH and blood lead when the 25 highest and 25 lowest blood lead values were compared for PTH values. In the same study, among 8 women with postmenopausal osteoporosis 1 year after treatment with PTH, calcitonin, and oral calcium, a significant reduction in blood lead concentrations was found. This suggests a relation between higher blood lead and a decrease in bone mass. In a later study of 15 patients with hyperparathyroidism, Osterloh and Clark²⁶ observed a statis-

Table 2. Geometric Mean (95% CI) Blood Lead by Demographic Characteristics and Measures of Bone Turnover

	n	Geometric Mean, μg/dL (95% CI)	P Value
Age, yr			
<50	25	5.5 (2.6, 16.6)	0.01
≥50	26	7.9 (2.8, 22.1)	
Gender			
Male	24	6.9 (2.5, 18.9)	0.52
Female	27	6.3 (2.8, 14.4)	
Dialysis vintage, yr			
<3.4	26	7.0 (2.4, 20.4)	0.39
≥3.4	25	6.2 (3.0, 13.1)	
Body mass index, kg/m ²			
<25	21	6.24 (2.9, 13.5)	0.46
≥25	30	6.9 (2.5, 19.1)	
Current smoking			
Yes	26	6.1 (2.4, 15.4)	0.22
No	25	7.2 (2.9, 17.7)	
Consume alcohol weekly			
Yes	4	6.4 (2.6, 15.5)	0.08
No	47	9.8 (3.2, 29.9)	
Parathyroid hormone, pg/mL			
<300	21	6.7 (2.6, 17.2)	0.87
≥300	30	6.6 (2.6, 16.4)	
Serum calcium, mg/dL			
<9.9	25	6.5 (3.7, 11.2)	0.75
≥9.9	26	6.8 (2.1, 22.1)	
Serum phosphorus, mg/dL			
<5.5	28	6.6 (2.7, 16.1)	0.94
≥5.5	23	6.7 (2.5, 17.6)	
Calcium phosphorus product (mg ² /dL ²)			
<55	37	6.5 (2.8, 15.4)	0.79
≥55	14	6.8 (2.2, 20.7)	

tically significant 14% reduction in blood lead concentrations after parathyroidectomy. However, when this decline was compared with changes in blood lead concentrations in control subjects and a reference group, the difference was no longer statistically significant, and the authors concluded that “in the high bone turnover state of hyperparathyroidism, blood lead concentrations are not likely to be different from other individuals.” The power of this study was limited however, and the authors could not rule out the possibility that hyperparathyroidism could influence blood lead levels.

A more recent study that included 60 patients with primary hyperparathyroidism also failed to

find a significant decrease in blood lead concentrations after parathyroidectomy. Initial blood levels were not different between patients with primary hyperparathyroidism and their normal healthy control counterparts, and the authors concluded that hyperparathyroidism does not lead to “hazardous lead release from bone.”²⁷ Only in patients with PTH levels >150 pg/mL (n = 23) was there a modest but statistically significant reduction in blood lead and urinary lead excretion subsequent to the parathyroidectomy. The authors also noted a significant correlation between PTH and blood lead concentration in this subgroup of their patients. This suggests that severe hyperparathyroidism may cause release of lead from bone into blood. However, overall, bone resorption was not an important mechanism contributing to elevated blood lead levels.

In sum, previous studies examining the relation between PTH and blood lead concentrations are confined to relatively small numbers of patients with primary hyperparathyroidism and normal kidney function. These studies remain equivocal as to whether hyperparathyroidism significantly influences blood lead levels. The absence of a significant relation in these populations could be attributed in part to scarcity of patients with an abnormal body burden of lead. In such patients, the total bone lead stores would be relatively small and changes due to PTH effects may not therefore be easily detectable. Even in patients with markedly elevated bone lead stores, the absolute magnitude of lead would be 5 to 6 orders of magnitude lower than bone calcium, and a 10% to 15% increase in blood lead concentration after bone resorption could not easily be detected above blood lead measurement error. It is also possible that bone lead may be sequestered in a less accessible compartment, and may be relatively resistant to resorption.

In the current study, we examined the relation between PTH and tibia lead in a group of patients with ESRD. Thirty of 51 patients in this study had PTH levels ≥300 pg/mL and could be considered to have secondary hyperparathyroidism.²⁴ Yet, there were no differences between blood and tibia lead levels in these patients compared with values in 14 dialysis patients who had “normal” PTH values (150

Table 3. Adjusted Mean Difference of Log-Transformed Blood Lead by Measures of Bone Turnover

	Age and Gender Adjusted		Full-Adjusted*	
	Mean Difference (SE)	P value	Mean Difference (SE)	P Value
Parathyroid hormone ≥300 pg/mL	-0.028 (0.13)	0.83	-0.022 (0.14)	0.87
Serum calcium ≥9.9 mg/dL	-0.010 (0.13)	0.94	-0.042 (0.13)	0.75
Serum phosphorus ≥5.5 mg/dL	0.011 (0.14)	0.93	0.026 (0.14)	0.85
Calcium phosphorus product ≥55 mg ² /dL ²	0.021 (0.16)	0.90	0.023 (0.17)	0.89

* Adjusted for age, gender, current smoking, education greater than high school, and dialysis vintage.

to 299 pg/mL) or 7 patients with “low” PTH values (<150 pg/mL). These observations indicate that PTH status does not influence blood or bone lead concentrations in ESRD patients on maintenance hemodialysis. The absence of an effect of PTH on blood and tibia lead concentrations is demonstrated by lack of correlations between PTH and blood and tibia lead concentration levels, as well as absence of differences in these measurements in the subgroup with elevated PTH levels. Our study is unique in that it evaluated this relation in a relatively large number of dialysis patients, and it included bone lead measurements by x-ray fluorescence. Furthermore, the geometric mean blood lead concentration in these patients was 6.6 $\mu\text{g/dL}$, with 8 patients having blood lead concentrations above 10 $\mu\text{g/dL}$. Thus, this study represents a group of patients with higher blood lead levels than the US general population.² Similarly, the median bone lead concentration by x-ray fluorescence was 17 $\mu\text{g/g}$, including 20 patients with concentrations over 20 $\mu\text{g/g}$, consistent with a moderately increased body burden of lead.^{13,14}

Most of the patients enrolled in the current study were from poor neighborhoods in urban New Orleans, and therefore it is not surprising that they have relatively high lead exposure when compared to the general U.S. population. Nevertheless, given the moderately increased blood and bone lead levels, the absence of a relation between PTH and blood and bone lead levels in these ESRD patients increases the confidence in the conclusion that PTH does not have a significant effect on bone metabolism of lead. Based on the results of the current study, blood and bone lead measurements can be interpreted as accurate parameters of patients’ lead exposure regardless of PTH or kidney function.

Acknowledgments

This study was conducted through funding from National Institutes of Health grant No. P20 RR17659-01 from the COBRE Program of the National Center for Research Resources.

References

1. **Menke A, Muntner P, Batuman V, et al.** Blood lead below 0.48 micromol/L (10 microg/dL) and mortality among US adults. *Circulation* 2006;114:1388–94.
2. **Muntner P, Menke A, DeSalvo KB, et al.** Continued decline in blood lead levels among adults in the United States: the National Health and Nutrition Examination Surveys. *Arch Intern Med* 2005;165:2155–61.
3. **Vupputuri S, He J, Muntner P, et al.** Blood lead level is associated with elevated blood pressure in blacks. *Hypertension* 2003;41:463–8.
4. **Muntner P, He J, Vupputuri S, et al.** Blood lead and chronic kidney disease in the general United States population: results from NHANES III. *Kidney Int* 2003;63:1044–50.
5. **Brewster UC, Perazella MA.** A review of chronic lead intoxication: an unrecognized cause of chronic kidney disease. *Am J Med Sci* 2004;327:341–7.
6. **Emmerson BT.** Chronic lead nephropathy. *Kidney Int* 1973;4:1–5.
7. **Batuman V, Landy E, Maesaka JK, et al.** Contribution of lead to hypertension with renal impairment. *N Engl J Med* 1983;309:17–21.
8. **Batuman V.** Lead nephropathy, gout, and hypertension. *Am J Med Sci* 1993;305:241–7.
9. **Lin JL, Ho HH, Yu CC.** Chelation therapy for patients with elevated body lead burden and progressive renal insufficiency: a randomized, controlled trial. *Ann Intern Med* 1999;130:7–13.
10. **Loghman-Adham M.** Renal effects of environmental and occupational lead exposure. *Environ Health Perspect* 1997;105:928–39.
11. **Staessen JA, Lauwerys RR, Buchet JP, et al.** Impairment of renal function with increasing blood lead concentrations in the general population: the Cadmibel Study Group. *N Engl J Med* 1992;327:151–6.
12. **Emmerson BT.** Lead stores in patients with renal insufficiency. *Nephron* 1991;58:233–4.
13. **Wedeen RP, Van de Vyver FL, D’Haese PC, et al.** Bone lead and the diagnosis of lead nephropathy. *Contrib Nephrol* 1988;64:102–8.
14. **Van de Vyver FL, D’Haese PC, Visser WJ, et al.** Bone lead in dialysis patients. *Kidney Int* 1988;33:601–7.
15. **Todd AC.** Coherent scattering and matrix correction in bone-lead measurements. *Phys Med Biol* 2000;45:1953–63.
16. **Todd AC.** Calculating bone-lead measurement variance. *Environ Health Perspect* 2000;108:383–6.
17. **Todd AC.** Contamination of in vivo bone-lead measurements. *Phys Med Biol* 2000;45:229–40.
18. **Todd AC.** Calculating bone-lead measurement variance: printer’s correction. *Environ Health Perspect* 2000;108:A298.
19. **Todd AC, Ehrlich RI, Selby P, et al.** Repeatability of tibia lead measurement by x-ray fluorescence in a battery-making workforce. *Environ Res* 2000;84:282–9.
20. **Todd AC, McNeill FE.** In vivo measurement of lead in bone using a 109 Cd “spot” source. In: Ellis KJ, Eastman JD, Human Body Composition Studies. New York, Plenum Press, 1993: pp 299–302.
21. **Todd AC, Parsons PJ, Carroll S, et al.** Measurements of lead in human tibiae: a comparison between K-shell x-ray fluorescence and electrothermal atomic absorption spectrometry. *Phys Med Biol* 2002;47:673–87.
22. **Khalil-Manesh F, Tartaglia-Erler J, Gonick HC.** Experimental model of lead nephropathy, IV: correlation between renal functional changes and hematological indices of lead toxicity. *J Trace Elem Electrolytes Health Dis* 1994;8:13–9.
23. **Bushinsky DA, Monk RD.** Electrolyte quintet: calcium. *Lancet* 1998;352:306–11.
24. 2003 annual report: ESRD clinical performance measures project. *Am J Kidney Dis* 2004;44:A5–6, S1–92.
25. **Osterloh JD.** Observations on the effect of parathyroid hormone on environmental blood lead concentrations in humans. *Environ Res* 1991;54:8–16.
26. **Osterloh JD, Clark OH.** Effects of hyperparathyroidism on blood lead concentrations in man. *Environ Res* 1993;62:1–6.
27. **Osterode W, Winker R, Bieglmayer C, et al.** Effects of parathyroidectomy on lead mobilization from bone in patients with primary hyperparathyroidism. *Bone* 2004;35:942–7.