Routledge
Taylor & Francis Group

Archives of Environmental Health: An International Journal

ISSN: 0003-9896 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/vzeh20

Clinical Application of in Vivo Tibial K-XRF for Monitoring Lead Stores

Richard P. Wedeen M.D. , Antonia Ty , Iris Udasin , Elissa A. Favata & Keith W. Jones

To cite this article: Richard P. Wedeen M.D. , Antonia Ty , Iris Udasin , Elissa A. Favata & Keith W. Jones (1995) Clinical Application of in Vivo Tibial K-XRF for Monitoring Lead Stores, Archives of Environmental Health: An International Journal, 50:5, 355-361, DOI: 10.1080/00039896.1995.9935967

To link to this article: https://doi.org/10.1080/00039896.1995.9935967

Clinical Application of in Vivo Tibial K-XRF for Monitoring Lead Stores

RICHARD P. WEDEEN
Research Service
VA Medical Center
East Orange, New Jersey
and
Departments of Medicine, Preventive Medicine and Community Health, and Radiology
University of Medicine and Dentistry of New Jersey
New Jersey Medical School
Newark, New Jersey

ANTONIA TY
Department of Pediatrics
IRIS UDASIN
ELISSA A. FAVATA
Department of Occupational Medicine
University of Medicine and Dentistry of New Jersey
Robert Wood Johnson Medical School
and
The Occupational and Environmental Health Institute
Piscataway, New Jersey
KEITH W. JONES
Department of Applied Science
Brookhaven National Laboratory
Upton, New York

ABSTRACT. We used in vivo tibial K–x-ray fluorescence for clinical evaluation of bone lead stores in 31 patients suspected of excessive lead absorption. Four clinical situations were examined: (1) postchelation therapy, (2) renal failure, (3) home exposure, and (4) occupational exposure. K–x-ray fluorescence assisted in determining the magnitude of body lead stores in patients with known excessive lead exposure. Serial measurements revealed a reduction in bone lead that occurred over the years, during which there was an absence of continued exposure; this reduction occurred more rapidly during chelation therapy. Sustained high bone lead levels following chelation therapy in two children were consistent with elevated lead stores from prior pica. In a patient with renal failure, K–x-ray fluorescence demonstrated massive lead stores at a time when chelation testing was not possible. In other cases, bone lead levels indicated the possible contribution of lead nephropathy to renal diseases of other etiologies. In individuals exposed to lead during home renovations, K–x-ray fluorescence provided reassurance that past exposure did not result in elevated body lead stores decades later. In the occupational setting, K–x-ray fluorescence documented cumulative lead stores in workers whose exposures varied in intensity and duration. The examples discussed here show how physicians can use K–x-ray fluorescence to deal with practical questions of patient management. As the test becomes more generally available, its safety, specificity, and simplicity should make it an important alternative to cumbersome chelation tests and potentially misleading blood lead measurements.

THE CLINICAL value of in vivo tibial K–x-ray fluorescence (K-XRF) depends on the ability of this noninvasive technique to measure bone lead content through an entire cross-section of bone. The bone volume sampled approximates that obtained by needle or surgical biopsy. The lead K-XRF measurement has been validated by direct sampling of bone and plaster-of-Paris phantoms.[1] Interpretation of bone lead concentrations obtained by in vivo tibial K-XRF is based on the observations that (a) bone lead correlates well ($r = .9$) with $CaNa_2EDTA$ chelation tests[2,3] and (b) chelatable lead assesses body lead stores more reliably than other laboratory techniques that are available.[4–7] Given that the ethylenediaminetetraacetic acid (EDTA) chelation test

requires parenteral injection and prolonged (i.e., usually 24-h) urine collections, it is impractical for large-scale clinical application. K-XRF is, therefore, a potentially important diagnostic tool for the evaluation of individuals with suspected excessive past lead absorption.

In vivo tibial K-XRF measures cumulative body lead stores, 95% of which are retained in bone, with a biological half-life of approximately 2 decades. Lead accumulated in bone for many years presents an opportunity to assess the body lead burden by in vivo XRF, but these stores also provide a long-lived source of endogenous exposure. The reduction in blood lead by chelating agents is followed by a rebound as lead moves from bone to blood, down a concentration gradient created by lead chelate excretion. The net movement of lead from bone to blood continues until a new blood:bone equilibrium is reached at a lower concentration level for both tissues than existed prior to chelation. The goal of chelation therapy is to reduce bone lead stores to levels found in the general population. Patient management that does not account for the exchangeable bone lead pool risks return of the blood lead to near pretreatment levels within a few weeks of therapy, even in the absence of continued environmental exposure. Chelation regimens employed in children who have had relatively brief exposures may be insufficient for older individuals with respect to reducing bone stores and hence steady-state blood lead concentrations. Bone lead reflects chelatable lead, even though the chelatable component in blood is not identified clearly and may be influenced by numerous metabolic factors that control calcium homeostasis. The correlation of blood lead with chelatable lead is more problematic because the biological half-life of lead in blood is only about 1 mo.

Although many epidemiological studies have been performed for which K-XRF has been used to assess body lead burdens, the use of the technique as a diagnostic tool has not been stressed to the same extent. Our purpose here is to show that XRF can serve as a clinical diagnostic aid in the evaluation of patients suspected of excessive past lead absorption.

It should be noted that K-XRF differs from L-XRF, which was used by Rosen et al. in children.[4] The K-XRF method records the relatively high-energy K photons that penetrate 2 cm into cortical bone. The much weaker L x-rays, however, penetrate only the outermost 0.5 mm of subperiosteal bone. Calibration of L x-rays is difficult because of substantial soft-tissue absorption, whereas K x-rays can be calibrated accurately and normalized to the bone calcium content.[7,8] In vivo K-XRF is relatively independent of source-target geometry, except to the extent that distance affects sensitivity.

The cases presented here illustrate how K-XRF can be used to deal with practical diagnostic questions of patient management. Although the clinical care of individual patients is sometimes viewed as a medical experiment, individual patients do not exhibit the uniformity attained in groups selected for epidemiologic research. When examined in detail, each patient is not only unique, but key uncontrolled variables (e.g., intermittent exposure or chelation therapy) cannot be normalized by experimental design. In clinical medicine, interpretation of laboratory data is often speculative, but interpretation is nevertheless necessary for patient management. A wide range of diagnostic techniques for the evaluation of lead absorption has been used in the cases described here. This report suggests that some of these measurements may sometimes be avoided in the future, particularly the lead-mobilization test and bone needle biopsy, by using the noninvasive assessment of bone lead afforded by XRF.

Method

Bone lead was measured with a 5-cm-diameter high-purity germanium detector, a computer-based pulse height analysis system, and a sealed ^{109}Cd radioactive source. The procedures were essentially identical to those described previously,[7] except that in the present study the detector was placed at a 150° angle to the incident x-ray beam, rather than on the detector axis. Performance in the two geometries was comparable. The ratio of the intensity of the K-XRF emitted from the mid-shaft of the left tibia to the intensity of the elastically scattered x-rays, which arise entirely from calcium and phosphorous, was used to calculate the lead concentration. The bone lead concentration, expressed as μg/g wet weight (ww), was calculated by comparing the ratio to values obtained from plaster-of-Paris calibration phantoms and the reported estimate for the weight percentage of calcium in wet bone. A value of 14.7% was used for this conversion. It is important to note that the quantity actually measured was the weight ratio of lead to calcium and that the conversion to unit of wet weight required assumptions about the calcium content of the bone. Lead concentration wet weight divided by 0.55 provided lead concentration for bone mineral.

The minimum detection limit (MDL) for these determinations of ww, based on repetitive runs on a plaster-of-Paris phantom, was 5 ± 2 μg/g ww (i.e., approximately 10 μg/g bone mineral). The MDL for humans may not be as accurate because of the scattering from soft tissue. The K-XRF apparatus was calibrated prior to patient measurements, using lead-acetate/plaster-of-Paris phantoms. Calibration was verified by atomic absorption spectroscopy of samples of the phantoms and tibia bone biopsy samples obtained from amputated legs.[1] Precision and accuracy of the measurements were ± 20%.

Measurement of bone lead was made in 1/2 h, using a ^{109}Cd source (< 50 mCi, cases 1–11; 100 mCi, cases 12–25). Calibration was checked daily, using three lead-doped plaster-of-Paris phantoms, prior to and following in vivo measurements. Whole-body radiation dose from a 200-mCi source is estimated to be 0.3 mrem, compared with natural radiation of 186 mrem/y, intraoral x-ray radiation of 0.1 mrem, or whole-body exposure from a chest x-ray of 30 mrem. The absorbed organ equivalent dose for the skin during in vivo tibial K-XRF[8] is 178 mrem for the skin, 0.0056 mrem for the gonads, and 0.4 mrem for marrow.

Results

Application 1: effects of chelation therapy (Table 1). K-XRF demonstrated the return of body stores toward normal in a craftsman of stained glass who had repeated episodes of acute massive exposure (Case 1)[9]. An estimated 350 mg of lead had been chelated from this patient during a 1-y period. During the last 7 mo of chelation therapy, his tibial lead fell 83% (i.e., 46 to 8 μg/g) by K-XRF, whereas his iliac crest lead fell 78% (i.e., 64 to 14 μg/g) by atomic absorption spectroscopy of needle biopsy samples. During the same period, chelatable and blood lead fell 78% (3 206 to 726 μg/d and 40 to 23 μg/dl, respectively). Thus, in vivo tibial K-XRF demonstrated the efficacy of chelation therapy over time and contributed to the clinical decision to continue or terminate therapy. In similar cases in the future, in vivo tibial K-XRF can replace the EDTA lead-mobilization test and bone biopsies used to follow the efficacy of chelation therapy in reducing the body lead burden.

In vivo tibial K-XRF showed that a single course of chelation therapy with succimer in a 9-y-old child (case 2) with pica was insufficient to return bone lead to a normal level. Nine y after receiving six courses of chelation therapy this child has a bone lead of 53 μg/g ww. A single course of chelation with succimer resulted in a decrease in blood lead from 35 to 8 μg/dl, but her tibial lead remained elevated at 43 μg/g. Additional succimer therapy resulted in a further drop in bone lead to 16 ppm ww, with a blood lead of 33 μg/dl. This child may have had continued intermittent exposure to lead, presumably from lead dust, despite having stopped pica and having had her home lead-abated.[10] In another 6-y-old child (case 3), bone lead remained elevated at 35 ppm ww, despite five courses of $CaNa_2EDTA$ therapy. Given that the blood lead remained at 26 μg/dl, further chelation therapy was not undertaken. Two years earlier, this child's blood lead level was 114 μg/dl. Again, continued exposure was the most likely explanation for the persistent elevation in bone and blood lead levels.

In many clinical situations, measurement of bone lead content provided reassurance that past excessive exposure did not result in persistent and dangerous blood lead stores decades later. In a young woman (case 4) who received chelation therapy at age 3 y because of pica and blood leads as high at 70 μg/dl, XRF revealed a bone lead concentration of 16 ppm ww, with a blood lead of 5 μg/dl at age 21 y. Similarly, a 9-y-old girl (case 5) who had received chelation therapy at age 4 y had a tibial lead of 11 ppm, with a blood lead of 9 μg/dl.

K-XRF demonstrated a return of bone stores to normal in a firearms instructor (case 6) who had been chelated 1 y earlier with a 21-d course of 20–30 mg/kg succimer. During succimer therapy, lead-chelate excretion fell from a maximum of 4.9 mg/d to 0.33 mg/d, and his blood lead fell from 68 to 17 μg/dl. A year later his bone lead was 12 μg/g ww—well within the clinically acceptable range—thus indicating no further need for chelation.

Two construction workers who had been exposed to lead during demolition work and who had received intermittent succimer chelation therapy were examined by XRF (cases 7 and 8). Acute occupational exposure in these men resulted in elevated blood leads, but bone leads remained in the normal range after a relatively short duration of exposure.

Application 2: renal failure (Table 2). K-XRF revealed very high bone lead levels in a patient who was receiving hemodialysis and who developed devastating muscle weakness (case 9). This 52-y-old woman had persistent high-level exposure that resulted from pica, a practice she continued while in the hospital. This woman was found peeling paint that contained lead from the walls of her hospital room, and she admitted that she ate the paint. She had a blood lead of 82 μg/dl. A tibial lead of 120 μg/g ww (by K-XRF) established the diagnosis of lead poisoning, rather than the more usual proximal muscle weakness associated with chronic hemodialysis. It was impossible to perform a diagnostic chelation test because of end-stage renal disease.

K-XRF raised the possibility that excessive lead absorption contributed to renal failure in a lead worker (case 10) who developed rapidly progressive glomerular nephritis (RPGN). Blood lead was 23 μg/dl, and bone lead was 26 ppm ww. Although these values

Table 1.—Effects of Postchelation Therapy

Case no.	Sex	Age (y)	Exposure	Duration (y)	Blood lead (μg/dl)	Bone lead (ppm, wet weight)	Note
1	Male	54	Stained-glass craftsman	30	72		Rx
					40	46	Rx
					23	8	
2	Female	9	Pica	4	35	53	Rx
		10			23	43	
		11			33	16	
3	Female	6	Pica	4	26	35	Rx
4	Female	21	Pica	4	5	16	Rx
5	Female	9	Pica	4	9	11	Rx
6	Male	37	Firearms	13	17	12	Rx
7	Male	40	Construction	1	(40)	< 5	Rx
8	Male	36	Construction	1	(39)	< 5	Rx

Table 2.—Cases with Renal Failure

Case no.	Sex	Age (y)	Exposure	Duration (y)	Blood lead (μg/dl)	Bone lead (ppm, wet weight)	Note
9	Female	52	Pica	10	82	120	Dialysis
10	Male	49	PbO packer	16	23	26	RPGN
11	Male	58	Plumber	30	8	12	Scr 1.8

exceeded those generally found in populations absent unusual exposure, they were typical of the values expected in exposed lead workers who were not currently exposed.[3] Presumably, the blood lead level was higher at the time of past exposure. The contribution of chronic high-lead exposure to renal failure in this patient was unclear. Presumably, lead compounded the renal damage caused by RPGN. Although lead does not cause rapidly progressive glomerulonephritis, lead-induced interstitial nephritis could add to the renal damage dominated by the glomerular disease of unknown etiology.

A 58-y-old male plumber (case 11) who had soldered copper pipes for household plumbing for at least 30 y and who had hypertension, gout, and early renal failure (serum creatinine 1.8 mg/dl) was suspected of having excessive lead absorption. This suspicion was not supported by the finding of a blood lead of 8 μg/dl and a bone lead of 12 ppm ww.

Application 3: home exposure (Table 3). A craftsman of stained glass (blood lead of 46 μg/dl, bone lead < 5 μg/g ww) and 5 individuals (bone leads < 9 μg/g ww) believed to have been exposed to lead in their homes were found to have normal bone lead concentrations (cases 12–16). Despite the risks of excessive lead absorption associated with renovation of homes with leaded paint, the exposures encountered by these individuals were not sufficient in intensity and duration to leave a permanent elevation of bone lead stores. The fact that a transient elevation of blood lead was insufficient to raise bone stores was illustrated in case 16. Transient blood lead elevations without increases in long-term bone stores were also encountered in infants who exhibited pica. Accumulation of lead in the slow-turnover bone sites requires long-term exposure. One child exposed to lead dust only (no pica) had a blood lead of 11 μg/dl and a bone lead < 5 ppm ww (case 17). These patients were reassured that their cumulative lead stores were typical of the contemporary general population that is exposed to ambient lead.

Application 4: occupational exposure (Table 4). Four lead-battery workers who were 34–60 y of age (cases 18–21) and who had more than a decade of exposure had blood leads that ranged from 1 to 52 μg/dl and bone leads that ranged from 11 to 38 ppm. The highest blood and bone levels were in the same individual who had a history of additional exposure from working with handcrafted ceramic glazes. The blood leads in the battery workers were performed by unknown laboratories and were believed to be unreliable. A retired battery worker (case 22) from another factory

Table 3.—Summary of Cases Exposed at Home

Case no.	Sex	Age (y)	Exposure	Duration (y)	Blood lead (μg/dl)	Bone lead (μg/g, wet weight)
12	Female	54	Renovation	1	—	9
13	Female	55	Renovation	2	—	< 5
14	Female	29	Renovation	3	—	< 5
15	Male	63	Renovation	4	4	< 5
16	Male	31	Stained glass	10	46	< 5
17	Female	11	Pb dust	1	11	< 5

had a bone lead level expected following 3 decades of industrial exposure. Fifteen years earlier and following 23 y of exposure, his blood lead had been 93 μg/dl, and his chelatable lead (EDTA lead-mobilization test) was 9 mg lead/d—15-fold greater than normal.[6] Seven men (cases 23–29) employed in the manufacture of tetraethyl lead [ethyl(4)] and who had been removed from exposure for 2 y had bone lead levels that ranged from 6 to 22 ppm ww. Even though this small sample suggests that, following exposure to organic lead, bone lead is comparable with levels found subsequent to exposure to inorganic lead, conclusions about the metabolism of organic lead are not warranted because each of these men was exposed simultaneously to inorganic lead during the manufacture of tetraethyl lead. Despite the difficulty in interpretation, these XRF measurements in workers exposed to tetraethyl lead are the first recorded in this occupation and are therefore important.

Bone lead levels suggested that lead poisoning was not the cause of a variety of symptoms in a construction worker who had peripheral neuropathy of unknown etiology (case 30). His blood lead was 4 μg/dl, and his bone lead was 13 μg/g ww. Low bone lead was also found in a secondary smelter worker whose blood lead at the time of XRF was 36 μg/dl.

Discussion

Using the EDTA lead-mobilization test, we previously showed that, at the time of clinical evaluation, elevated body stores accounted for the development of tubulointerstitial nephritis in lead workers whose blood leads were within the Occupational Safety and Health Administration's (OSHA's) designated acceptable limits (i.e., < 40 μg/dl).[6] Similarly, chelation testing demonstrated that lead contributed to kidney disease in a surprisingly large number of patients who had hyperten-

Table 4.—Summary of Cases Who Were Exposed Occupationally

Case no.	Sex	Age (y)	Exposure	Duration (y)	Blood lead (μg/dl)	Bone lead (ppm, wet weight)	Note
18	Male	60	Battery	35	48	18	Retired—3 y
19	Male	57	Battery	38	27	22	Retired—1 y
20	Male	34	Battery	11	1	11	
21	Male	48	Battery	18	52	38	
22	Male	64	Battery	33	—	33	Retired—2 y
23	Male	66	Ethyl (4)*	14	18	22	Retired—3 y
24	Male	44	Ethyl (4)*	26	9	22	Retired—3 y
25	Male	57	Ethyl (4)	32	14	20	Retired—2 y
26	Male	52	Ethyl (4)	2	20	13	Rx
27	Male	38	Ethyl (4)	21	10	9	
28	Male	45	Ethyl (4)	18	21	8	Retired—3 y
29	Male	44	Ethyl (4)	2	21	6	Retired—3 y Rx
30	Male	51	Construction	40	4	13	
31	Male	26	Smelter	10	36	9	

*Ethyl (4) = tetraethyl lead.

sion and/or gout and renal failure.[11–15] Renal failure of nonlead etiology did not cause an increase in body lead stores, bone lead, or chelatable lead.[3] In 21 patients in whom low-level ambient exposure was reported previously, K-XRF showed bone leads within the expected normal range.[1]

Sufficient experience has now been gained by bone biopsy and in vivo tibial K-XRF to allow estimation of blood, bone, and chelatable lead levels that are expected, following different exposures in adults (Table 5). Comparisons between these tests are helpful because each depends uniquely on exposure dose (intensity) and duration (time), modulated by endogenous and environmental mediators of lead absorption and metabolism. Although each test measures a distinct aspect of lead metabolism, comparisons are helpful because each is used to assess body lead burden clinically.

The low-level environmental exposure that occurs from lead in water, food, air, and soil has adverse effects on the population as a whole in terms of neurobehavioral development, reproduction, newborn growth, blood pressure, and kidney function (Table 5). Following a lifetime of exposure to ambient environmental lead, blood leads are usually less than 20 μg/dl, and mobilizable lead (i.e., EDTA chelatable lead) is typically less than 600 μg/d. Tibial lead is less than 20 ppm ww, and the lead:calcium ratio is less than 160 μg lead/g calcium. Tibial lead concentrations are sometimes below the detection limit of current K-XRF instrumentation (i.e., approximately 5 ppm ww). The "integrated blood-lead index" used by Sommervaille[16] is less than 200 when the tibial lead concentration is less than 20 μg/g bone mineral (i.e., approximately 11 μg/g ww). The adverse effects of this type of low-level ambient lead absorption are not identified by physicians for individual patients, but they are detected in epidemiologic studies of relatively large populations. The phrase "normal lead levels" refers to levels found in adults who have encountered no unusual exposure.

A somewhat higher level of absorption is encountered from intermittent moderate exposure that arises from (often unrecognized) exposure sources (e.g., dust from leaded paint and eating utensils). Intermittent, moderately high exposure that occurs for many years may contribute to hypertension, kidney disease, stroke, heart disease, gout, and gouty nephropathy in the general population.[11–15] These adverse effects can be detected in individual patients but are usually attributed to nonspecific factors (e.g., aging process). The possible contribution of lead is overlooked unless the source of exposure has been identified independently or if chelation testing is undertaken. Blood leads range between 20 and 50 μg/dl, chelatable lead ranges between 600 and 1 000 μg/d, and bone leads reach levels expected after occupational exposure (i.e., 20–60 μg/g ww, with a lead:calcium between 160 and 600 μg lead/g calcium). The integrated blood lead index of Somervaille et al.[16] approximates 500. This approximates the adult bone lead levels reached after 10 y of occupational exposure, with a blood lead averaging about 30 μg/dl. The second National Health and Nutrition Survey (NHANES II) data suggested that approximately 1% of the general population sustains excessive lead exposure (i.e., blood leads greater than 30 μg/dl) that usually goes unrecognized.[18]

Classical lead poisoning (i.e., abdominal colic, peripheral neuropathy, encephalopathy, and anemia) is encountered at high, persistent levels of exposure that arise from pica, occupational exposure, improperly glazed ceramics, lead-crystal glassware, leaded paint chips, and contaminated alcoholic drinks.[15] When high exposure is continuous but not incapacitating, blood lead exceeds 50 μg/dl over a number of years—and may be as high as 100 μg/dl; chelatable lead exceeds 1 000 μg/d; and tibial leads exceed 60 μg lead/g calium). The integrated blood lead index of Somervaille et al.[16] approximates 1 000. This level of exposure approximates the adult bone lead levels reached after years of occupational exposure, with blood leads averaging 50 μg/dl.

Table 5.—Levels of Lead Exposure: Sources, Symptoms, and Body Stores

Exposure	Sources	Symptoms	Blood lead (μg/dl)	EDTA Test† (μg/3 d)	Tibial‡ (μg/g)	
					Lead	Lead : calcium
1. Low, continuous (ambient)	Water Food Air Soil	IQ, neuropathy Reproduction Stillbirths Hypertension Neonatal growth	< 20	< 600	< 20	< 160
2. Moderate, occasional (intermittent)	Paint dust Cans, toys Pewter Enamelware Crystal Silverplate Stationary	Hypertension Kidney (TIN)§ Gout Behavior/mental GI	20–50	600–1 000	20–60	160–600
3. High, persistent (chronic)	Pica Work Glazes Moonshine Paint dust	Colic Neuropathy Encephalopathy Anemia Prerenal hypertension Kidney (TIN)§	> 50	> 1 000	> 60	> 600
4. Massive (acute)	Pica Work Glazes Moonshine Paint dust	Transient: Hypertension Fanconi syndrome Colic Neuropathy Encephalopathy Anemia Prerenal hypertension Kidney (TIN)§	> 100	> 1 000	Surface?	

*See text for exposure-time factors.
†Values for adult 70-kg male.
‡Wet weight—determined by in vivo tibial K-XRF.
§TIN = tubulointerstitial nephritis.

Acute massive exposure produces the classical symptoms of lead poisoning more regularly than does high, persistent chronic exposure, but it is of shorter duration and is more intense. Exposure time may be as brief as a few weeks, but it usually does not exceed a few months because of incapacitating symptoms. Acute lead poisoning was formerly common in children with pica and is still encountered with disturbing frequency in workers at lead-battery recovery plants. Encephalopathy, transient hypertension, proximal tubule reabsorptive defects (the Fanconi syndrome), and prerenal azotemia occur in this setting.

Given the short duration of exposure, bone lead accumulation may be limited to the periosteal surfaces and trabecular bone. A peak in the local surface concentration may not be detected by K-XRF, which measures the total bone lead across 2 cm of cortical bone. K-XRF measurements following acute massive lead absorption will reflect the time and duration of exposure to lead, the time at which the measurement is made, and the growth rate of bone at the time of—and following—exposure. Inasmuch as exposure may occur for only a few months, bone lead—as assessed by K-XRF—may be low (e.g., < 10 μg/g ww), with an integrated blood lead index approximating 250.[16]

Ultimately the place of XRF in clinical medicine will be determined by physicians who are confronted with practical questions in patient management. As the test becomes more available, its safety, specificity, and simplicity should make it an important addition to the physician's armamentarium. At present, in vivo tibial K-XRF is suitable for the detection of excessive lead stores. Advances in the technology in the future may make it equally useful for characterizing the distribution of bone lead in a normal population in which the mean bone lead value approximates 3 μg/g ww.[3]

At present, when suspicion of excessive past lead absorption is high, an XRF measurement of cumulative bone stores may prove valuable for clinical decision making. In vivo tibial K-XRF can document excessive body lead stores in complex situations, such as hemodialysis, when bone lead metabolism is largely unknown. K-XRF is of value in monitoring the efficacy of chelation therapy and in determining the end point for such therapy. Bone lead determinations can document normal body lead stores in individuals with high

past exposure and in whom decades of negative lead balance restored body burdens to normal without pharmacologic chelation. In these situations, the efficacy of preventive measures can be established, and chelation therapy can be avoided. With respect to others with potential excessive exposure to lead, the finding of normal tibial bone levels can provide reassurance while the search for other causes of nonspecific symptoms is pursued.

* * * * * * * * * * *

This work was supported in part by the Research Service, U.S. Department of Veterans Affairs, and by the U.S. Department of Energy under contract no. DE-AC02-76CH00016 (KWJ).

Submitted for publication June 15, 1994; accepted for publication November 3, 1994.

Requests for reprints should be sent to Richard P. Wedeen, M.D., VA Medical Center, East Orange, NJ 07018-1095.

* * * * * * * * * * *

References

1. Wedeen RP, Batuman V, Quinless F, Williams FH, Jr, Bogden J, Schidlovsky G, Jones KW. In vivo x-ray fluorescence (XRF) for assessing body lead stores. In: In Vivo Body Composition Studies. Ellis KJ, Yasumura S, Morgen W., Eds. London, England: The Institute of Physical Sciences in Medicine, 1987; pp 357–362.
2. Hu H, Pepper L, Goldman R. Effect of repeated occupational exposure to lead, cessation of exposure, and chelation on the levels of lead in bone. Am J Ind Med 1991; 20:723–35.
3. Van de Vyver FL, D'Haese PC, Visser WJ, Elseviers MM, Knippenberg LJ, Lamberts LV, Wedeen RP, DeBroe ME. Bone lead in dialysis patients. Kidney Internat 1988; 33:601–07.
4. Rosen JF, Markovitz ME, Bijur PE, Jenks ST, Weilopolski L, Kalefezra JA, Slatkin DN. L-line x-ray fluorescence of cortical bone lead compared with $CaNa_2EDTA$ test in lead-toxic children: public health implications. Proc Natl Acad Sci 1989; 86:685–89.
5. Inglis JA, Henderson DA, Emmerson BT. The pathology and pathogenesis of chronic lead nephropathy occurring in Queensland. J Pathol 1978; 124:65–76.
6. Wedeen RP, Mallik DK, Batuman V. Detection and treatment of occupational lead nephropathy. Arch Int Med 1979; 139:53–57.
7. Jones KW, Schidlovsky G, Williams FH, Jr, Wedeen RP, Batuman V. In-vivo determination of tibial lead by K x-ray fluorescence with a Cd-109 Source. In: In Vivo Body Composition Studies. Ellis KJ, Yasamura S, Morgan WD, Eds. London, England: Institute of Physical Sciences in Medicine, 1987; pp 363–73.
8. Wedeen RP. In vivo tibial XRF measurement of bone lead. Arch Environ Health 1990; 45:69–71.
9. Batuman V, Wedeen RP, Bogden J, Balestra DJ, Jones K, Schidlovsky G. Reducing bone lead content by chelation treatment in chronic lead poisoning. An in vivo X-ray fluorescence and bone biopsy study. Environ Res 1989; 48:70–76.
10. Graziano JH, Lolacono NJ, Meyer P. Dose-response study of oral 2,3-dimercaptosuccinic acid in children with elevated blood lead concentrations. J Pediatr 1988; 113:751–57.
11. Batuman V, Landy E, Maesaka JK, Wedeen RP. Contribution of lead to hypertension with renal failure. N Engl J Med 1983; 309:17–21.
12. Colleoni N, D'Amico G. Chronic lead accumulation as a possible cause of renal failure in gouty patients. Nephron 1986; 42:32–35.
13. Emmerson BT. Chronic lead nephropathy. Kidney Internat 1973; 4:1–3.
14. Batuman V, Landy E, Maesaka JK, Wedeen RP. Contribution of lead to hypertension with renal failure. N Eng J Med 1983; 309:17–21.
15. Wedeen RP. Poison in the Pot: The Legacy of Lead. Carbondale, IL: Southern Illinois University Press, 1984.
16. Somervaille LJ, Chettle DR, Scott MC, Tennant DR, McKiernan MJ, Skilbeck A, Trethowan WN. In vivo tibial measurements as an index of cumulative exposure in occupationally exposed subjects. Br J Ind Med 1988; 45:174–81.
17. Wedeen RP. Blood lead levels, dietary calcium, and hypertension. Ann Intern Med 1985; 102:403–04.
18. Mahaffey, KR, Annest JL, Roberts J, Murphy MSPH. National estimates of blood lead levels: United States, 1976–1980. Association with selected demographic and socioeconomic factors. New Engl J Med 1982; 307:573–79.