Measuring Body Lead Burden by pXRF

From Needleman's Tooth-Lead Baseline to Aaron Specht et al's Portable Bone-Lead Analysers

By Elizabeth O'Brien, Lead Scientist and Lead Advisor, orchestrated by Ian Smith, Systems Analyst, using OpenClaw on top of Claude AI and Ollama local AI models where possible, on solar-powered infrastructure. *© The LEAD Group Inc. November 2026*

Lead does not stay in the blood. Most of the lead in a body is locked away in the hard tissues, the bones and the teeth, where a blood test cannot see it. This bibliography follows one of the most useful ideas in lead science, that if the damage is written into hard tissue, you can read the record directly, from the earliest use of children's baby teeth through to today's hand-held bone-lead X-ray fluorescence scanners. It follows on from The Tooth Fairy Project of Professor Herbert Needleman (LEAD Action News v23n3, article 3) [LID 29231].

Herbert Needleman is article one in this research. He worked with children's shed teeth because teeth fall out on their own, and because a child is happy to hand a tooth to the tooth fairy for testing, and he used them to show that lead lowers children's IQ. That is the seed of everything that follows: lead leaves a permanent record in mineralised tissue, so the goal becomes reading that record, first in teeth, then in bone, first with cumbersome technology, then with portable field devices.

Bone lead was hard to reach. For a long time it could only be measured after death, on cremated bone ash. (See for instance the previous article in this issue of *LEAD Action News*, vol 24 no 3.) When X-ray fluorescence (XRF) first made living bone-lead measurement possible, the XRF analysers were large enough to walk into, and there were so few of them in the world that The LEAD Group had to tell Australian and New Zealand clients to fly to North America each time they wanted a bone-lead measurement. Portable, hand-held XRF analysers changed that: now the analyser can be taken to the people who need measuring, living or dead, though even now they are used for bone lead almost only for research in North America.

The irony is that XRF analysers are everywhere. Mining exploration companies, who have all the money they need, have bought them by the thousand since the 1950s – even field-portable ones called pXRF analysers - to measure metals in ore bodies. Those same companies never seem to have "enough money", so they say, to buy an XRF analyser dedicated to measuring bone lead in their own workers or in the communities near their metalliferous or coal mines. Yet bone-lead XRF is the best available way to know an organism's true body lead burden, and repeat testing is the best way to know whether exposure is still rising, or whether lead-detox is bringing the lead body burden down.

Needleman HL, Gatsonis CA. Low-level lead exposure and the IQ of children: a meta-analysis of modern studies. JAMA. 1990;263(5):673-678.

https://doi.org/10.1001/jama.1990.03440050067035 [LID 6925]

The baseline of the series. Pooling twelve rigorous childhood studies, seven using blood lead and five using tooth lead, it clinched the case that even low-dose lead lowers children's IQ, and did so partly by

reading lead out of shed baby teeth. That use of a hard, lead-storing tissue as a permanent exposure record is the conceptual seed of everything that follows: if lead's harm is written into teeth and bone, then measuring that tissue directly becomes the prize.



2013 Volcano Art Prize (VAP) Entry. Artist: Tony Lennon. Title: Lead in bones in lead. Lead-Safety Message: As the lead stored in your bones leaches into your blood as you age, so you get closer to the grave. URL: https://volcanoartprize.com/portfolio-item/lead-in-bones-in-lead/ [LID 17464]

Chettle, DR; Scott, MC; & Somervaille, LJ, Lead in bone: sampling and quantitation using K X-rays excited by 109Cd, Environ Health Perspect. 1991 Feb;91:49-55. https://pmc.ncbi.nlm.nih.gov/articles/PMC1519364/pdf/envhper00387-0052.pdf [LID 20070]

At around the same time as The LEAD Group was forming (at least in the mind of this Co-Founder), from researchers at the School of Physics and Space Research, University of Birmingham, England, UK, this February 1991 paper was the first to use X-ray fluorescence to measure lead in human bone in vivo. Chettle et al noted that this could be done from a mobile facility, although the devices themselves (pictured) were not hand-held, therefore not regarded as portable.

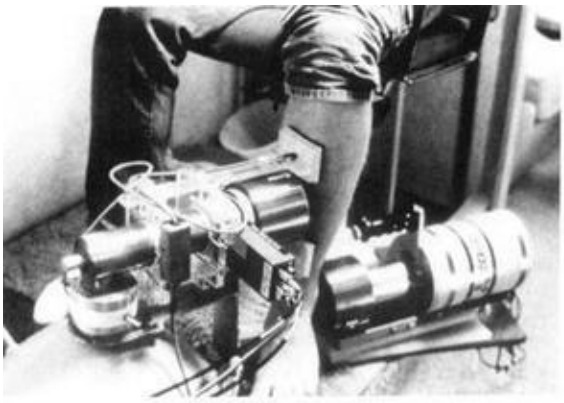


FIGURE 7. Simultaneous *in vivo* bone lead measurements of tibia and calcaneus.

Specht AJ, Weisskopf M, Nie LH. Portable XRF technology to quantify Pb in bone in vivo. Journal of Biomarkers. 2014;2014:398032. https://doi.org/10.1155/2014/398032 [LID 28082]

Although portable XRF or pXRF for paint lead analysis – to investigate cases of childhood lead poisoning - had also been becoming more common since the 1950s, especially in the USA, this Specht et al 2014 paper appears to be the proof-of-concept research for the entire bone lead portable XRF or bone lead pXRF era. Where the standard bone-lead method (K-shell XRF, written as KXRF) needed a large, fixed, hard-to-site apparatus, Specht's team developed a portable system for L-shell XRF, written as LXRF, built around a customised commercial analyser (Thermo Fisher's Niton XL3t), that quantifies lead in living bone in about three minutes, with a detection limit of 2.9 parts per million (2.9 ppm) through 2 millimeters (2 mm) of soft tissue and results that track KXRF closely. The primary difference between K-shell and L-shell XRF comes down to X-ray energy levels: portable XRF (pXRF) devices typically operate at lower voltages (around 50 kV) and must rely on lower-energy L-shell emissions for heavy elements like lead, whereas traditional non-portable KXRF systems use high-energy radioisotopes or high-voltage lab tubes to excite the deeper, higher-energy K-shell electrons. Specht et al 2014 is the paper that declared the technology ready to leave the laboratory for large human population studies.

Specht AJ, Lin Y, Weisskopf M, Yan C, Hu H, Xu J, Nie LH. XRF-measured bone lead (Pb) as a biomarker for Pb exposure and toxicity among children diagnosed with Pb poisoning. Biomarkers. 2016;21(4):347-352. https://doi.org/10.3109/1354750x.2016.1139183 [LID 28083]

The first real-world clinical test in children. In 115 children (average age 5.7 years) at Xinhua Hospital in Shanghai, portable LXRF was compared to KXRF bone lead as a biomarker and blood lead in elevated blood lead level (EBLL) children in China, confirming bone lead measurements from pXRF analysers as a useful lead biomarker in the young. Along the way it measured the blood-lead half-life in these young children at about ten days (9.96 days plus or minus 3.92 days), a number that matters for anyone trying to interpret a single blood result or a series of blood lead results in a young child.

Specht AJ, Mostafaei F, Lin Y, Xu J, Nie LH. Measurements of strontium levels in human bone in vivo using portable X-ray fluorescence (XRF). Applied Spectroscopy. 2017;71(8):1962-1968. https://doi.org/10.1177/0003702817694383 [LID 28101]

This paper used the same portable tool but it was pointed at a different element. It shows portable XRF can measure bone strontium, not just lead, in living people, validated in 238 children, replacing the older bulky radioisotope method. Its importance to this collection is that it proves the hardware is a general in-vivo bone-metal reader; and because measurement of bone strontium (Sr) is vital to determining the effectiveness of Sr supplementation. Which is commonly used for the treatment of osteoporosis, this Specht et al 2017 paper may be the key to convincing researchers, pathology labs, specialist bone health clinics, lead-exposure mining and smelting companies and workers unions outside of North America to import pXRF analysers, which can then also be used for bone lead biomonitoring. There is every good reason for everyone who is lead exposed to be bio-monitored for lead with a bone pXRF analyser and also assessed for early signs of osteoporosis because
Specht AJ, Parish CN, Wallens EK, Watson RT, Nie LH, Weisskopf MG. Feasibility of a portable X-ray fluorescence device for bone lead measurements of condor bones. Science of the Total Environment. 2018;615:398-403.
https://doi.org/10.1016/j.scitotenv.2017.09.123 [LID 28106]

The first step off the human body and into wildlife for Specht et al. On excised California condor bones, portable-XRF bone lead agreed closely with gold-standard ICP-MS (r≈0.92), even through simulated soft tissue. Condors die of lead poisoning from spent ammunition, so this showed a hand-held device could read a scavenger's cumulative lead burden, and, by extension, flag the same ammunition risk to people.



2022 Volcano Art Prize (VAP) Entry. Artist: Lucinda Curran. Title: How much lead is in your bone broth. Lead-Safety Message: According to research, sequestered lead in bones can be mobilised and result in markedly higher lead concentrations when compared to tap water (Monro, Leon & Puri, 2012). Given the ever-increasing use of bone broth for a variety of health conditions, great caution needs to be taken when considering bone broth diets. Description of Work: digital art. Image of soup bowl: jenvit keiwalinsarid from Pexels. URL:
https://volcanoartprize.com/portfolio-item/how-much-lead-is-in-your-bone-broth/ [LID 26404]

Specht AJ, Weisskopf M, Nie LH. Childhood lead biokinetics and associations with age among a group of lead-poisoned children in China. Journal of Exposure Science and Environmental Epidemiology. 2019;29(3):416-423 (online 2018). https://doi.org/10.1038/s41370-018-0036-y [LID 28148]

Using repeat visits in 250 children, it shows the blood-to-bone lead relationship strengthens over time and, strikingly, that lead's blood half-life depends on age, about 7 days in one-to-three-year-olds versus about 19 days in older children. The lesson, that children clear lead from blood faster than adults, means a single childhood blood test is an even briefer snapshot than assumed, and strengthens the case for bone as the durable more telling record.

Specht AJ, Kponee K, Nkpaa KW, Balcom PH, Weuve J, Nie LH, Weisskopf MG. Validation of X-ray fluorescence measurements of metals in toenail clippings against ICP-MS in a Nigerian population. Physiological Measurement. 2018;39(8):085007. https://doi.org/10.1088/1361-6579/aad947 [LID 28107]

Extends XRF to a sample you can post in an envelope, toenail clippings, which capture a longer exposure window than blood and store at room temperature. Against ICP-MS in 20 Nigerian adults, XRF toenail manganese correlated strongly (R=0.91), while lead was weaker (R=0.32). The genuinely new part is a calibration that corrects for each clipping's weight and thickness, making toenail XRF workable for large, low-cost field studies.



2024 Volcano Art Prize (VAP) Entry. Artist: Jennifer Chuah. Title: Three Skull Kings. Lead-Safety Message: Lead stored in your bones can actually kill you so contribute to or join The LEAD Group's project to have bone lead testing available in Australia by portable X-Ray Fluorescence (pXRF) by October 2025. Description of Work: Coloured pencil drawing collaged in Powerpoint. URL: https://volcanoartprize.com/portfolio-item/three-skull-kings/ [LID 28175]

Specht AJ, Dickerson AS, Weisskopf MG. Comparison of bone lead measured via portable X-ray fluorescence across and within bones. Environmental Research. 2019;172:273-278. https://doi.org/10.1016/j.envres.2019.02.031 [LID 28081]

Answers a practical worry: does it matter which bone you measure? Across 31 cadavers and multiple cortical and trabecular sites, portable-XRF bone lead was consistent between bones within a person, and more internally consistent (rho≈0.4) than older KXRF over the same range (rho≈0.2). Because the low-energy portable device reads the cortical shell every bone shares, you can measure almost anywhere and get a comparable answer, a large practical simplification.

Specht AJ, Zhang X, Goodman BD, Maher E, Weisskopf MG, Nie LH. A dosimetry study of portable X-ray fluorescence in vivo metal measurements. Health Physics. 2019;116(5):590-598. https://doi.org/10.1097/hp.0000000000000971 [LID 28080]

The safety paper. Using three independent methods, physical dosimeters and Monte Carlo simulation, it pins down exactly how small the radiation dose is: a standard bone measurement delivers a whole-body effective dose of about 3.4 microsieverts (toenail about 2.0), a trivial fraction of everyday background radiation. This is the evidence a hospital or ethics committee needs before approving routine, repeated testing.

Bhatia M, Specht AJ, Ramya V, Sulaiman D, Konda M, Balcom P, Sunderland EM, Qureshi A. Portable X-ray fluorescence as a rapid determination tool to detect parts-per-million levels of Ni, Zn, As, Se and Pb in human toenails: a South India case study. Environmental Science & Technology. 2021;55(19):13113-13121.
https://doi.org/10.1021/acs.est.1c00937 [LID 28104]

Pushes toenail XRF to a multi-metal, population-scale screen. In 97 people near Chennai, India, portable XRF matched ICP-MS well for nickel, zinc and lead (no proportional bias) but poorly for arsenic and low-level selenium, mapping precisely where the cheap, non-destructive method can and cannot replace the expensive one for high-throughput monitoring.

Zhang X, Wells EM, Specht AJ, Weisskopf MG, Weuve J, Nie LH. In vivo quantification of strontium in bone among adults using portable X-ray fluorescence. Journal of Trace Elements in Medicine and Biology. 2022;74:127077.
https://doi.org/10.1016/j.jtemb.2022.127077 [LID 28087]

The adult companion to the 2017 strontium study, extending in-vivo bone strontium to 76 US and 29 Chinese adults aged 38 to 95, and quantifying how measurement uncertainty rises with soft-tissue thickness (from 1.0 to 2.4 ppm at 2 to 7 mm). It confirms portable XRF as a bone-health tool across the adult age range, and exposes the same soft-tissue limit that governs bone-lead precision.

Specht AJ, Steadman DW, Davis M, Bartell SM, Weisskopf MG. Bone lead variability in bone repository skeletal samples measured with portable X-ray fluorescence. Science of the Total Environment. 2023;880:163197. https://doi.org/10.1016/j.scitotenv.2023.163197 [LID 28088]

The definitive "which bone, how much does it vary" study for lead. Across five skeletal sites (mid, proximal and distal tibia, ilium and cranium) in a bone repository, portable-XRF lead did not differ significantly between sites, yet the paper still recommends the tibia as the standard site so studies and individuals can be compared like for like. Detection limit about 2.1 ppm. This is the methods anchor for standardising field work.



2025 Volcano Art Prize (VAP) Entry. Artist: Grandma Lead. Title: Test Shooters for Lead. Lead-Safety Message: A possibly lead poisoned shooter confessed on September 11, 2025 to assassinating Charlie Kirk. As a 3rd year electrical apprentice, the 22 year old shooter would have been protected from occupational lead exposure but there need to be regulations to protect child shooters from lead exposure that can cause frontal lobe damage, homicidal violent crime and brainrot incoherence. US criminologists and lead poisoning prevention advocates need to write to their congressional representatives demanding that he and all indicted shooters be bone lead and blood lead tested ASAP after being taken in to custody. Description of Work: Collage of photos from YouTube video by The Rational National, Meme'd To Death: The Brainrot Incoherence Of Charlie Kirk's Alleged Killer Lead-Safety Message by Elizabeth O'Brien, AKA Grandma Lead. URL: https://volcanoartprize.com/portfolio-item/test-shooters-for-lead/ [LID 28919]

Hampton JO, Lohr MT, Specht AJ, et al. Lead exposure of mainland Australia's top

avian predator. Environmental Pollution. 2023;332:122004. https://doi.org/10.1016/j.envpol.2023.122004 [LID 28147]

Brings the method home to Australia. Using portable XRF on bone from 62 wedge-tailed eagles (Aquila audax) collected between 1996 and 2022, it detected lead in 84 per cent of them, the first serious look at ammunition-derived lead in Australia's largest raptor. It shows the hand-held device working on an opportunistic carcass collection and puts an Australian, wildlife face on the global lead-ammunition problem.

Gomes RAMP, Santos AL, Catarino L. Elemental analysis using portable X-ray fluorescence: guidelines for the study of dry human bone. International Journal of Paleopathology. 2024;44:85-89. https://doi.org/10.1016/j.ijpp.2023.12.004 [LID 28105]

The "how to do it properly" note (not a Specht paper, included as the standards counterpart). Aimed at archaeology and palaeopathology, it standardises portable-XRF procedure on dry bone, sample choice and preparation, calibration, run time, accuracy checks and data validation, so that results from different laboratories can actually be pooled and compared. It is the missing rulebook that lets a whole field's numbers add up.

Specht AJ, Adesina KE, Read DE, Weisskopf MG. Benchtop X-ray fluorescence to quantify elemental content in nails non-destructively. Science of the Total Environment. 2024;918:170601. https://doi.org/10.1016/j.scitotenv.2024.170601 [LID 28146]

Swaps the hand-held for a benchtop XRF to fix toenail XRF's weak spot, its detection limit. It brings non-destructive nail measurement close to ICP-MS (lead R^2=0.92, copper 0.95), with median detection limits around 0.2 micrograms per gram across 23 elements. The trade-off, laboratory-bound but far more sensitive, complements the portable devices used in the field.



2024 Volcano Art Prize (VAP) Entry. Artist: Elizabeth O'Brien. Title: Avoid strokes as you age. Lead-Safety Message: My motivation for asking people to join me in self-experimenting with lead detox methods and now pushing for bone lead testing by pXRF in Australia, is my mother. She had notifiable (5-7 µg/dL) blood lead levels between 5 strokes in her final 21 years, the first stroke when she was just three years older than I am now. Description of Work: iPhone 8 photos collaged in Paint and Powerpoint. URL: https://volcanoartprize.com/portfolio-item/avoid-strokes-as-you-age/ [LID 28190]

Farmer JG, Specht A, Punshon T, et al. Lead exposure across the life course and age at death. Science of the Total Environment. 2024;927:171975. https://doi.org/10.1016/j.scitotenv.2024.171975 [LID 28086]

Reads three tissues to time-stamp a lifetime of lead. In 208 skeleton donors (born 1910 to 1960) it uses tooth enamel (childhood), tooth cementum (adulthood) and bone (later life) to place lead exposure at different ages and relate it to age at death, finding that adult-life cementum lead tracked age-at-death more closely than bone lead. It closes the loop back to Needleman's teeth: the same idea, now used to reconstruct a whole life's exposure.



2024 Volcano Art Prize (VAP) Entry. Artist: Elizabeth O'Brien. Title: pXRF Bone Lead Testing. Lead-Safety Message: #Grandma Lead says: In our lead safe future, everyone will have access to bone lead testing by portable X-Ray Fluorescence (pXRF) using a Niton XL3t GOLDD+ (made by Thermo-Fisher Scientific, USA). And all earthlings should have less lead in our bones if Australian registered voters sign the Circular Economy for Lead Petition EN6714. Description of Work: iPhone 13 photo and text added in Powerpoint. URL: https://volcanoartprize.com/portfolio-item/pxrf-bone-lead-testing/ [LID 28164]

Specht AJ, Hoover C, Grier T. Portable X-ray fluorescence for bone lead measurement: current approaches and future directions. Current Environmental Health Reports. 2024;11(3):443-451. https://doi.org/10.1007/s40572-024-00450-x [LID 28085]

The field's stock-take, written by its main driver. This review traces XRF bone-lead measurement from KXRF to portable XRF, weighs their accuracy and limits (portable XRF reads cortical bone only, but faster and with comparable results), and argues that "legacy" lead exposure demands a revival of bone-lead surveillance because blood alone misses the cumulative burden. It is the single best entry point to the whole story.

Specht AJ, Sayam ASM, Parish CN, Hauck TJ, Watson RT, McClure CJW, Weisskopf MG. Bone lead measurements of live condors in field to assess cumulative lead exposure. Environmental Science and Pollution Research. 2024;31(44):56308-56313. https://doi.org/10.1007/s11356-024-34950-y [LID 28084]

The payoff of the condor thread, now on live birds in the wild. Portable XRF measured bone lead in vivo in the tibiotarsus of 64 free-living California condors, and that bone lead correlated with each bird's summed lifetime of blood-lead tests, exactly the chronic, cumulative signal that a blood lead series of tests misses. It points to bone lead guiding treatment for an endangered species, and models how the same in-field, in-vivo cumulative reading could one day serve people.