PLAIN LANGUAGE SUMMARY

Examining Biogenic and Diagenetic Lead Exposure with Synchrotron Radiation X-ray Fluorescence Imaging of Experimentally Altered Bone: Plain Language Thesis Summary[1,2]

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ABSTRACT
This plain language summary summarizes research recently undertaken as part of an MA thesis (September 2020) at the Department of Archaeology and Anthropology (University of Saskatchewan). This thesis set out to map patterns of lifetime lead exposure versus post-mortem lead contamination in bone samples from both modern Saskatchewan and archaeological individuals. In addition to measuring the lead levels of each sample, this thesis used a synchrotron radiation-based element mapping technique to map the distribution of lead within each bone sample on a microscopic scale. When lead is taken up into bone during an individual's life, it is incorporated into actively forming bone, leading to spatial patterns that reflect individual life histories of lead exposure. When bones are contaminated by lead in the burial environment, the lead is typically found at the outer surfaces and large pores of bone. Therefore, this element mapping technique is useful in helping archaeologists distinguish between lifetime and post-mortem lead exposure and can provide important information about individual histories of lead exposure for archaeological and modern populations alike.

Keywords: bioarchaeology; Saskatchewan; lead; diagenesis; bone; synchrotron radiation

An estimated one in three children experience some from lead (Pb) poisoning annually around the world (UNICEF & Pure Earth, 2020), with lead causing an estimated 1.06 million deaths in 2017 (IHME, 2017). Though it is an extremely harmful and toxic substance, lead has nonetheless been widely used by humans for thousands of years in everything

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[2] The thesis summarized here is available online through Harvest, the University of Saskatchewan Research Archive (https://harvest.usask.ca/handle/10388/13074). Chapters from this thesis have been previously published as review articles in Synchrotron Radiation News (Simpson et al., 2019) and Archaeological and Anthropological Sciences (Simpson et al., 2021), and as a research article in Science of the Total Environment (Simpson et al., 2021).

from paint and cosmetics to plumbing and food containers. Research into the lead burden of modern and past populations alike is instrumental to the understanding of morbidity and mortality today and in the past. The interdisciplinary thesis (Simpson, 2020) summarized here set out to investigate patterns of lifetime lead exposure and post-mortem lead contamination in bone samples from modern Saskatchewan individuals and archaeological individuals from Antigua and Lithuania.

Bones can reflect years to decades worth of lead exposure, as lead gradually accumulates in bone until natural bone remodeling processes recycle stored lead back into the bloodstream. Up to 97% of the human body's consumption of lead becomes stored in the skeleton (Barry, 1975). Because of lead's natural affinity for bone and bone's ability to survive in the archaeological record, the field of bioarchaeology (the study of past humans based on their skeletal remains) is uniquely suited to examine lead exposure in the past. Lead concentrations and isotopic ratios accumulate in an individual's bones for years to decades during their lifetime, and represent a large window into lead exposure in the past. There are several techniques at the bioarchaeologist's disposal that can measure the levels and isotopes of lead and other trace elements in bones and teeth, but these techniques often encounter limitations. First, it is difficult to account for the effects of diagenesis—the physical, chemical, and bacterial changes that bones and teeth undergo in the burial environment, including chemical contamination of bones. The bioarchaeologist must consider how much of the lead within a bone or tooth is actually from a person's exposure to lead during their lifetime, and how much lead has seeped into the bone from the burial environment. Second, when dealing with lead levels alone, these techniques often cannot give us information about the timeline of lead exposure. For instance, was someone exposed to lead consistently throughout their lifetime, or did it occur in a few acute events? Did the exposure occur earlier on in life or right before death?

Element mapping techniques are one potential means of addressing both limitations. Synchrotron radiation X-ray fluorescence imaging (SR-XFI) is a technique that can be used to map the distribution and intensity of trace elements (including lead) in bone on a microscopic scale. Because bone constantly remodels, it contains a mosaic of both mature and newly formed microscopic structures. By examining which microscopic structures in bone contain lead, researchers can gain insights into an individual's lifetime patterns of lead exposure. This mapping technique may also be used to identify areas of diagenetic contamination from lifetime lead exposure in bone (Swanston et al., 2012), though up to this point, controlled, experimental research investigating this was lacking.

My thesis used both conventional techniques and SR-XFI to answer several research questions including: Are there differences in the microscopic spatial distribution of lead for lifetime (biogenic) versus diagenetic exposure? What can we learn about lifetime lead exposure patterns from modern individuals from Saskatchewan? To answer these questions, I obtained donor bone samples from human cadavers through collaboration with the University of Saskatchewan's Body Bequeathal Program. These bones had never been buried in the ground and exposed to potential sources of diagenetic lead, and therefore reflected an individual's long-term biogenic exposure to lead during life. I kept one half of each sample unaltered, reflecting biogenic lead exposure, and simulated diagenetic contamination in the other half of each sample. I hypothesized that the respective biogenic and diagenetic lead exposure patterns observed in the modern bone samples would match the patterns observed previously in archaeological samples (Swanston et al., 2012, 2018; Rasmussen, 2019). Lead pollution in the

Canadian context peaked decades ago when lead use was far more commonplace in mainly daily life activities like leaded gasoline, plumbing, and paint. As the modern Saskatchewan individuals in my sample were older adults, they were alive during this peak era (pre-1990s) and their bones likely contained some structures that formed during this period. I hypothesized that older, more mature bone microstructures would be more enriched in lead than newly formed microstructures.

Bone samples from two archaeological individuals were also analyzed. One sample was from an individual interred in a colonial Antigua British Royal Navy hospital cemetery, where it is known that the Navy personnel experienced high levels of lead poisoning (Giffin et al., 2017). The other sample was from an individual interred in a nineteenth to twentieth-century Lithuanian mausoleum, where diagenetic lead contamination of the remains is suspected to have taken place.

The lead levels of each bone sample were measured with a technique called Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Archaeological bone samples had lead levels roughly twenty-nine to fifty-nine times higher than the modern humans from Saskatchewan but these results provided little in the way of helping to differentiate between biogenic and diagenetic lead exposure. SR-XFI maps of lead in bone scanned at the Advanced Photon Source synchrotron showed clear differences for biogenic and diagenetic lead exposure in both modern and archaeological bone. Diagenetic lead was primarily found along the outer edge of the bone sample and in some large pores or canals, while biogenic lead was found throughout the bone sample, in microstructures that were actively forming at the time of exposure. This shows that element mapping techniques can be used to help distinguish lifetime from diagenetic lead exposure in archaeological bone, which can aid bioarchaeologists in interpreting the skeletal lead burden in past populations.

The SR-XFI element maps of lead in bone also echoed this finding of comparatively lower lead exposure among the modern Saskatchewanian individuals compared to the archaeological individuals. Within the modern bone samples, lead was either found within mature bone microstructures as opposed to newly formed bone structures or found fairly consistently across the bone sample. This suggests higher lead exposure in the past or fairly steady low level lead exposure, respectively. While the sample size of this study is too small to draw conclusions about the larger Saskatchewan population, these findings are promising from a public health perspective. This research was both the first ever skeletal lead study of a modern human population from Saskatchewan and the first application of SR-XFI to examine lead exposure in a modern Canadian population. Future research can continue to use this technique, or techniques like it, to help differentiate between biogenic and diagenetic lead in archaeological bone and explore lifetime patterns of lead exposure for modern and archaeological populations alike.

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