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The Franklin expedition: What sequential analysis of hair reveals about lead exposure prior to death

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ABSTRACT

Hypotheses on why the 1845 Franklin expedition to the Arctic ended in tragedy include suggestions of lead (Pb) poisoning. Hair keratin was sequentially analysed for isotopic ratios and lead concentrations from remains of a Franklin expedition member, tentatively identified as HDS Goodsir, buried on King William Island in the Canadian arctic. We approximated lead concentrations in Goodsir's blood to elucidate a pattern of lead burden in the three months prior to death.

Lead isotope ratios in Goodsir's hair were almost identical to that of the bodies discovered on King William and Beechey Islands. The lead concentrations (73.3–84.4 ppm) reflect more immediate exposure and are high by today's standards. Estimated blood lead concentrations (~53.6–61.3 μg/dL), suggest that lead exposure, while high, may not have been sufficient to cause worsening physical and mental symptoms. Lead ingestion likely occurred during the expedition; however, it is probable that multiple factors are responsible for the loss of the expedition, of which lead exposure may have been one.

1. Introduction

In 1845, British explorer Sir John Franklin departed on a voyage to find the North-West Passage, a sea route that links the Atlantic Ocean to the Pacific. The expedition was to complete its mission within three years and return home, but the two ships, HMS *Erebus* and HMS *Terror*, and the 129 men aboard vanished in the Arctic. The last Europeans to see them alive were the crews of two whaling ships on Baffin Bay in July 1845, just before they entered the Arctic Archipelago (Beattie and Geiger, 2014). Several rescue expeditions were unsuccessful in locating Franklin and his men, and in 1859, a note from the expedition was discovered on King William Island. It was dated May 1847 and indicated that all was well, but an addendum, written in April 1848, stated that 24 members, including Sir John Franklin, had died by that date and the remaining 105 left their icebound ships and aimed to reach safety via the Back River on the Canadian mainland.

Researchers have debated the reasons why the Franklin expedition ended in tragedy, including the possibility of lead (Pb) poisoning from the pipes on the ships and/or the sealed tins that provided the main source of food (e.g., Battersby, 2008; Kowal et al., 1989). Studies show that lead concentrations in the bones of three expedition members who died in the first winter at Beechey Island in the Canadian High Arctic were high relative to the present day (Beattie, 1985; Kowal et al., 1989), and this has resulted in theories that lead toxicity contributed to the demise of the expedition. It is hypothesized that ingestion of lead from contaminated canned provisions caused acute, exogenous poisoning that weakened the men and impaired their cognitive function (Kowal et al., 1989; Beattie and Geiger, 2014). One difficulty with this theory is that bone remodels approximately every 10–50 years (Raisz, 1999), so lead concentrations in the bones would be heavily influenced by the lead burden acquired prior to boarding the ships bound for the Arctic.

Hair is not remodeled after formation; therefore, its composition reflects diet and physiological stress at the time of tissue formation (Williams et al., 2011; D'Ortenzio et al., 2015). Hair grows between 0.35 and 0.44 mm per day and based on the growth rate of 0.35 mm/day, 1 cm of hair corresponds to approximately one month of elapsed time (Saitoh et al., 1967; Williams et al., 2011). Because hair grows

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incrementally, and once formed is an inert tissue, its elemental composition provides a short-term record of lead exposure for the weeks/months/years (depending on the length of hair) preceding death (Appenzeller et al., 2007). As there is an approximate 20-day delay between concentrations of lead in the first cm of hair and the corresponding monthly blood level (Rabinowitz et al., 1976; Clarkson and Magos, 2006), inferences about lead toxicity based on elemental evidence are necessarily general, but human hair can provide an important supplement to, or confirmation of skeletal evidence.

To investigate this problem, we sequentially analysed lead (Pb) concentrations and isotopic ratios of lead in the hair keratin from an individual who was buried on King William Island during the Franklin expedition. He died sometime between September 1846 and early 1848, so his hair provides a window on lead burden at a later stage in the expedition than did the soft tissue analyses of the Beechey Island individuals, who died early in 1846 (Beattie and Geiger, 1987, 2014). We used lead concentrations in the hair to estimate concentrations in blood. This was done to elucidate the pattern of lead concentrations in the three months prior to death, to gain insight into the lead burdens acquired during the expedition and to determine how deleterious the lead exposure may have been.

2. Materials and methods

2.1. The human remains tentatively identified as those of HDS Goodsir

Human remains from the Franklin expedition were recovered in 1869 by Charles Francis Hall, an arctic explorer, from a grave in south-eastern King William Island. They were shipped to Britain and interred in 1872 in a casket below a memorial to the Franklin expedition at the Old Royal Naval College Chapel, in Greenwich, London. The remains were initially identified in the 19th century as belonging to one of HMS *Erebus's* lieutenants, Henry Le Vesconte, however a re-evaluation of the individual by Mays et al. (2011) has determined that this identification is unlikely to be correct. Osteological examination, strontium and oxygen isotopic analysis, and a forensic facial reconstruction suggests that the remains were more likely those of HDS Goodsir, a 26 to 29-year-old male, born in Anstruther, Fife, eastern Scotland. He was an Assistant Surgeon on the expedition and received his medical training in Edinburgh (Mays et al., 2011). The remains were mainly skeletonised, although many bones bore dried remnants of soft tissue. Osteological analysis found no evidence of scurvy or tuberculosis, but evidence of a dental infection in the left maxilla could have contributed to cause of death (Mays et al., 2011). In addition to the skeletal elements, the interment contained remains of blankets and clothing in which the body had been interred on King William Island. The hair analysed in this report was found adhering, via soft tissue decomposition products, to the textiles in large clumps (Mays et al., 2011). It appears highly unlikely that the hair represents inadvertent extraneous contamination after the burial was exhumed. On the contrary, its intimate association with the textiles in which the body was wrapped strongly suggests that it belongs to the buried individual.

2.2. Sequential preparation of hair keratin

A bundle of 55 hair fibers were gently removed from the textile with stainless steel tweezers and the application of drops of distilled water to avoid any damage to the hair. All hair fibers were washed with distilled water, examined with a digital microscope, and photographed. Every hair ($n = 55$) was photographed under 120× magnification using a Nikon SMZ 1000 digital microscope to identify the hair root, which is located closest to the scalp. The hair root was used to orientate the hair fibers properly in preparation for sequential lead analysis. The hair roots were slightly enlarged, usually with some epithelial tissue attached (Fig. 1a–b) (Williams et al., 2011; D'Ortenzio et al., 2015). The hair strands were stored temporarily in labelled Teflon containers.

The bundle of hair fibers was laid out on a template of laminated metric graph paper. A glass sheet was placed over the graph template that was cleaned with methanol. The hair samples were placed on the graph template and using tweezers, the hair was gently aligned along the graph template with the proximal (root) end facing left or on the zero line. The fibers were pinched together at the centimeter mark, and a stainless-steel scalpel blade was carefully rolled across the hair fibers to cut the segment. Following this procedure, the hair samples were divided into three sequential 1 cm segments which were then stored separately in labelled Teflon containers. The 1 cm segments were ultrasonicated first with distilled water for 10 min then soaked in methanol and chloroform (2:1 v/v) to remove surface contamination (O'Connell and Hedges, 1999; Williams et al., 2011). The methanol-chloroform solution was changed after 10 min and hair segments were rinsed again with distilled water and ultrasonicated for 10 min after the change of fresh solution. The hair was rigorously cleaned using methanol-chloroform solution to distinguish between lead that was endogenous, namely absorbed into the blood and incorporated into the hair matrix, versus lead that was exogenous; derived from external contamination. Using this technique during the washing step ensured that exogenous lead was removed, whereas the endogenous lead remained. Hair segments were then air-dried for 24 h to remove any remaining water and weighed on a microbalance. They were then transferred to pre-cleaned Teflon containers and shipped to Dallas for analysis. The weight of the hair fibers was between 1.44 and 1.81 mg.

2.3. Lead (Pb) analysis

Upon receipt, an aliquot of ^{205}Pb spike was added to the containers and the hair samples were decomposed in 1 mL of purified nitric acid (lead content < 1 ng/L). After evaporation to dryness, the residue was dissolved in 200 μL of 0.6 M hydrobromic acid and Pb was separated on miniature anion exchange columns. Lead isotopic ratios were measured on a Finnigan MAT 261 multicollector, thermal ionization mass spectrometer. As ^{205}Pb does not occur in nature, both the lead isotope ratios and the lead concentration can be obtained from the same analysis. Long-term stability of the mass spectrometer was monitored by routinely measuring the lead standard SRM 981 to ensure reproducibility of the instrument and all ratios reported have been corrected by a factor of 0.145% per atomic mass unit.

2.4. Blood level concentration of lead extrapolated from lead in the hair segments

Blood lead concentrations were estimated from lead values from the hair (ppm) using Sanna et al.'s (2007) study, where the relationship between lead in hair and lead in blood was significantly and positively correlated. The blood lead level required to produce hair lead concentrations was estimated using the ratio; blood (μg/dL): hair (ppm) which was approximately 1:0.73.

3. Results

Elemental and isotopic results, and estimated blood concentrations of lead are presented in Table 1. Sequential analysis of the hair starting with FH3, which was the hair segment furthest from the scalp and represented lead concentrations three months prior to death, was the highest at 84.2 ppm. Lead concentrations dropped to 73.3 ppm in the month just prior to death. A study by Grandjean (1978) found blood-lead values observed in the hair of individuals with occupational lead exposure ranged from 58 to 63 μg/dL and are approximately of equivalent value to blood-lead values that we report. As anticipated, the isotopic ratios for lead were consistent throughout all three segments of hair showing little variability.

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