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"Hartnell's time machine" reprise: Further implications of zinc, lead and copper in the thumbnail of a Franklin expedition crewmember

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ABSTRACT

Christensen et al. (2016) have described the application of synchrotron micro-X-ray fluorescence mapping, stable isotopic analysis and laser-ablation inductively-coupled plasma mass spectrometry to provide a unique and dynamic time scale of the concentration of metals in the thumbnail of John Hartnell who was a member of the 1845 British Royal Naval "Franklin expedition" which met a fatal end in the Arctic. Their finding of low levels of lead and zinc in Hartnell's thumbnail has questioned the supposed lead-poisoning of the crew and introduced a new hypothesis that zinc deficiency contributed to the loss of the expedition. It is proposed here that their innovative and intriguing hypothesis might be considered cautiously in light of uncertainty as to the reliability of nail as a biomarker of zinc deficiency and calculations that the Royal Navy's provisioning of its Arctic ships would have provided adequate dietary zinc. Whilst there may be difficulty in interpreting the *absolute* levels of zinc in the nail, the change in the levels over time may provide unique insights. It is agreed that exponential increases in levels of zinc, copper and lead seen in the weeks prior to Hartnell's death from pulmonary tuberculosis might reflect endogenous release of the metals due to tissue catabolism. It is further proposed that the increase in those metals also reflects the administration by the expedition's surgeons of lead, zinc and copper-containing medications which were widely used to relieve the distressing symptoms of tubercular disease.

1. Introduction

1.1. Investigating the loss of the Franklin expedition

The deaths of all 129 men of the British Royal Naval expedition of 1845 to establish a Northwest Passage under the command of Captain Sir John Franklin remain the greatest single loss of life in Polar exploration (Lambert, 2009; Potter, 2016; Savours, 1999). Significant understanding of the expedition's fate began with autopsies of the permafrost-preserved bodies of John Hartnell, William Braine and John Torrington who died at the first winter quarters at Beechey Island (Beattie and Geiger, 2004). In addition to evidence of tubercular disease, levels of lead in their bone and soft tissue, and in skeletal remains from King William Island, led to the hypothesis that the crew had suffered lead poisoning (Amy et al., 1986; Keenleyside et al., 1996; Kowal et al., 1989; Notman and Beattie, 1995). The supposed role of scurvy (Cyriax, 1939) has not been supported by skeletal analysis (Mays et al., 2015).

1.2. Chronology of accumulation of zinc, copper and lead in John Hartnell

Most recently, Christensen et al. (2016, Figs. 5 and 6) have applied synchrotron micro-X-ray fluorescence mapping, stable isotopic analysis and laser-ablation inductively-coupled plasma mass spectrometry to the thumbnail of John Hartnell to provide a time-line of concentrations of zinc, lead and copper from June 1845 until his death on 4th January 1846. They describe the nail as a "time machine" that relates the chronology of events in Hartnell's life to variation in levels of the metals. The present focus is upon the implications of their innovative analysis for the crew's nutritional state, lead poisoning and medical intervention by the expedition's surgeons.

1.3. The supposition of zinc deficiency

Christensen et al. (2016, Fig. 5) showed that one month after leaving England in May 1845, the level of zinc in the inner layer of Hartnell's nail was ~30 ppm. The level varied cyclically between ~30 ppm and ~60 ppm to mid-September when the peak level then increased to 65 ppm until mid-November (the later exponential increase prior to Hartnell's death is discussed in Section 4.2 below). Christensen et al. compared the levels of zinc in Hartnell's nail with "reference data" showing nail zinc of 80–191 ppm in 96 healthy inhabitants (aged 1–76 years)

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of northern Sweden (Rodushkin and Axelsson, 2000) and proposed that Hartnell's nails reflected a chronic zinc deficiency that may have affected the whole crew. This proposal must be considered cautiously for several reasons. First, healthy subjects are reported with lower levels of nail zinc than Hartnell (İlhan et al., 2004). Secondly, the WHO endorses serum or plasma zinc as a biomarker of the metal (de Benoist et al., 2007), a standard that is supported by a systematic review which concludes that there are insufficient studies of several potential biomarkers, including nail, to determine whether they reflect zinc status (Lowe et al., 2009). Thirdly, Weiringa et al. (2015) observe that there is no specific biomarker related to zinc deficiency *per se*, being consistent with the WHO's observation that whilst serum and plasma zinc are biomarkers of the metal they do not necessarily reflect the individual's zinc status.

The evidence above makes it difficult to determine whether the levels of zinc in Hartnell's nail indicate a deficiency and must question the validity of the conclusion of Christensen et al. that "severe zinc deficiency played a greater role than lead in the demise of the Franklin expedition". However, whilst the *absolute* level of zinc may be difficult to interpret, it will be shown in Sections 4.1 and 4.2 that the relative changes in the levels of zinc, copper and lead over time do provide a unique and valuable insight to the course of Hartnell's illness and his medical treatment in the weeks leading to his death. Thus, the implications of variation in levels of the metals in the nail over time would still justify the metaphor of the "time machine" applied by Christensen et al.

First, however, it is important to examine whether there is objective evidence to support two circumstances proposed by Christensen et al. that might have contributed to a crew-wide deficiency in zinc. They proposed that a deficiency might have occurred if the canned meats supplied to the expedition were "not appreciably zinc-rich" and if, in addition, a proportion of those provisions were unfit for consumption thus causing a reduction in the daily meat ration. If both conditions occurred, then zinc deficiency might have affected the whole crew.

These proposals can be examined objectively, first by calculating whether the zinc content of Royal Naval Arctic rations would satisfy present-day recommendations for dietary intake of the metal; secondly by considering the evidence for unfit provisions; thirdly by considering whether the expedition's progress was consistent with a crew-wide deficiency of zinc.

2. Royal Naval Arctic rations

2.1. Calculating the zinc content of meat rations

Rations for Royal Naval ships sent in search of Franklin were described by Armstrong (1858 p14) and allow estimation of a typical crew's dietary zinc. Table 1 shows the weekly rations of preserved (canned) meats, salt beef and salt pork after Armstrong, and the "imaginary" scale of rations composed by Cyriax (1939, p 42) from his assumed consumption of provisions by the expedition. The expedition's preserved meats consisted principally of roasted beef and mutton (ADM 114/17, 1845). Estimation of their zinc content must be cautious because they may not be fully comparable with present-day products. Visual inspection of preserved meat from the Franklin expedition conserved in the National Maritime Museum shows it to be predominantly lean meat with moderate fat content (Royal Museums, Greenwich). The "Composition of Foods Integrated Dataset" of Public Health England (2015) provides the zinc content (mg/100 g) of 23 samples of roasted "lean and fat" cuts of beef and lamb (as "mutton" is not included the zinc values for "lamb" have been selected instead). Calculation of the median zinc content of those meats estimates the expedition's preserved meats to have contained 4.6 mg zinc/100 g. Values for salt beef and salt pork are 4.6 mg/100 g and 0.9 mg/100 g, respectively, from the nutrient tables of the US Department of Agriculture (2008).

The Royal Navy's weekly ration per man was 1190.7 g of preserved meats and 595.3 g of salt beef or pork (issued on alternate days), therefore providing a daily total of 12.5 mg zinc according to the values estimated above (see Table 1). However, Armstrong (1858, p 14) observed that a serving of preserved or salt meat typically contained 75% meat product, the rest being jelly, sinew or bone. When a 25% reduction is applied to Table 1, the intake of zinc is 9.4 mg/day. Cyriax's estimate corresponds to 7.4 mg/day when reduced. As the current recommended range of dietary zinc for men in the UK is 5.5 to 9.5 mg/day (www.nhs.uk/conditions/vitamins-minerals/), the Royal Naval rations would have provided adequate zinc.

2.2. The quality of provisions

Christensen et al. (2016) observed that concerns were raised in 1850 that the preserved meats supplied by the manufacturer, Goldner, might have been unfit for consumption, potentially leading to starvation if rations had to be reduced (see Cyriax, 1939). They propose that zinc deficiency might then have affected the whole crew. Whilst it is correct that Goldner was involved in a later scandal concerning his products, a British Parliamentary investigation found that his supplies to the Franklin expedition had been of satisfactory quality and exonerated him: Lloyd and Coulter (1963, pp. 96–102) noted the neglect of this fact by some historians.

2.3. The expedition made good progress over the first two years

If Franklin and his experienced officers had been faced with depleted provisions and a crew debilitated by zinc deficiency within only months of leaving England, it would seem unlikely that they would have continued with the mission. Franklin's sailing orders explicitly required him to protect the health of his men and he had full authority to return home if the ships required resupply rather than commit the crew to hardship (Orders 9 and 10: Ross, 1855). The expedition is known to have overwintered successfully from 1845 to 1846 at Beechey Island where the men constructed winter quarters, conducted man-hauled sledge operations and built cairns: such strenuous activities would seem incompatible with a crew-wide zinc deficiency. The fact that in May 1847, two years after departure, a senior officer signed off a report stating "*All Well*" (and he underlined it for emphasis) would seem inconsistent with any serious circumstances affecting the crew. Moreover, the Inuit

Table 1
The weekly ration per man of preserved and salt meats (g) and the equivalent daily zinc content (mg) according to the Royal Navy schedule of Arctic victualling (Armstrong, 1858) and Cyriax's (1939) "imaginary" rations consumed by the Franklin expedition.

Rations		Preserved meat	Salt beef	Salt pork	Zinc total (mg)	
					Weekly	Daily
Royal Navy	Weekly ration (g)	1190.7	595.4	595.4		
	Zinc content (mg)	54.8	27.4	5.4	87.6	12.5
	Zinc–25% (mg)[a]	41.1	20.5	4.0	65.6	9.4
Cyriax	Weekly ration (g)	680.4	680.4	680.4		
	Zinc content (mg)	31.3	31.3	6.1	68.7	9.8
	Zinc–25% (mg)[a]	23.5	23.5	4.6	51.6	7.4

[a] Denotes the 25% reduction in zinc content to correct for jelly, sinew and bone in preserved and salted meats (see Section 2.1)