

# A Critical Assessment of the Oral Condition of the Crew of the Franklin Expedition

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**ABSTRACT.** Little is known about the fate of the crew of the Franklin expedition after they sailed from England in 1845. Scant physical evidence and limited Inuit testimony have fueled speculation that the crew had scurvy, had been poisoned by lead, or had botulism or tuberculosis. The Schwatka expedition (1878–80) documented that several Inuit families had observed sailors of the Franklin expedition dragging ship's boats in Washington Bay on the southwest coast of King William Island, Nunavut, Canada. The Inuit reported that the men appeared thin and the mouths of some of them were hard, dry, and black. Many Franklin scholars believe from this description that the surviving crews were suffering from scurvy and possibly lead poisoning. Using a systematic review of the medical literature to assess the Inuit testimony, we reviewed 1718 citations. With this approach, we identified a new and plausible explanation for the wasting and oral conditions ascribed to some of the survivors. We believe that miliaary tuberculosis resulting in adrenal insufficiency (or Addison's disease) may have resulted in the oral and physical symptoms witnessed by the Inuit. Scurvy and lead exposure may have contributed to the pathogenesis of Addison's disease, but the hypothesis is not wholly dependent on these conditions. The tuberculosis-Addison's hypothesis results in a deeper understanding of one of the greatest mysteries of Arctic exploration.

**Key words:** Arctic; Northwest Passage; Sir John Franklin; oral; dental; scurvy; lead poisoning; tuberculosis; Addison's disease

**RÉSUMÉ.** Nous savons peu de choses sur le destin des membres d'équipage de l'expédition Franklin, partie de l'Angleterre en 1845. Les preuves physiques insuffisantes et les témoignages restreints des Inuits ont alimenté des hypothèses selon lesquelles les membres de l'équipage auraient eu le scorbut, auraient été empoisonnés au plomb, ou encore, auraient été atteints de botulisme ou de tuberculose. Selon des documents de l'expédition Schwatka (1878-1880), plusieurs familles inuites auraient vu des marins de l'expédition Franklin en train de tirer des embarcations dans la baie de Washington, sur la côte sud-ouest de l'île King William, au Nunavut, Canada. Les Inuits auraient dit que les hommes étaient d'apparence maigre et que la bouche de certains était dure, sèche et noire. D'après cette description, de nombreux érudits spécialisés dans l'expédition Franklin en ont déduit que les membres d'équipage ayant survécu souffraient de scorbut, voire d'empoisonnement au plomb. Le dépouillement systématique de la documentation médicale visant à évaluer les témoignages des Inuits nous a permis de prendre connaissance de 1718 citations. Grâce à cette démarche, nous avons découvert une nouvelle explication plausible au dépérissement et à l'état de la bouche attribués à certains survivants. Nous croyons que la tuberculose miliaire donnant lieu à une insuffisance surrénale (ou maladie d'Addison) pourrait avoir causé les symptômes buccaux et physiques décrits par les Inuits. Le scorbut et l'exposition au plomb pourraient avoir contribué à la pathogenèse de la maladie d'Addison, bien que l'hypothèse ne dépende pas entièrement de ces conditions. L'hypothèse de la tuberculose (maladie d'Addison) permet de mieux comprendre l'un des plus grands mystères de l'exploration de l'Arctique.

**Mots clés :** Arctique; passage du Nord-Ouest; sir John Franklin; oral; dentaire; scorbut; empoisonnement au plomb; tuberculose; maladie d'Addison

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## INTRODUCTION

In 1845 the British Admiralty sponsored what was hoped to be the final expedition to the Arctic to complete the transit and mapping of the remote northern coast of North America, an area commonly referred to as the “Northwest Passage.” The expedition, commanded by Sir John Franklin RN, consisted of two Royal Navy vessels: HMS *Erebus*

and HMS *Terror*. The vessels left England on 19 May 1845 and were captained by Captain Francis Rawdon Moira Crozier (*Terror*) and Commander James Fitzjames (*Erebus*) (Cyriax, 1939). In July 1845, the ships were observed by the whaling ship *Prince of Wales* near Lancaster Sound (Cyriax, 1939).

Three years passed without any further contact, and by 1848 concern for the safety of the expedition prompted

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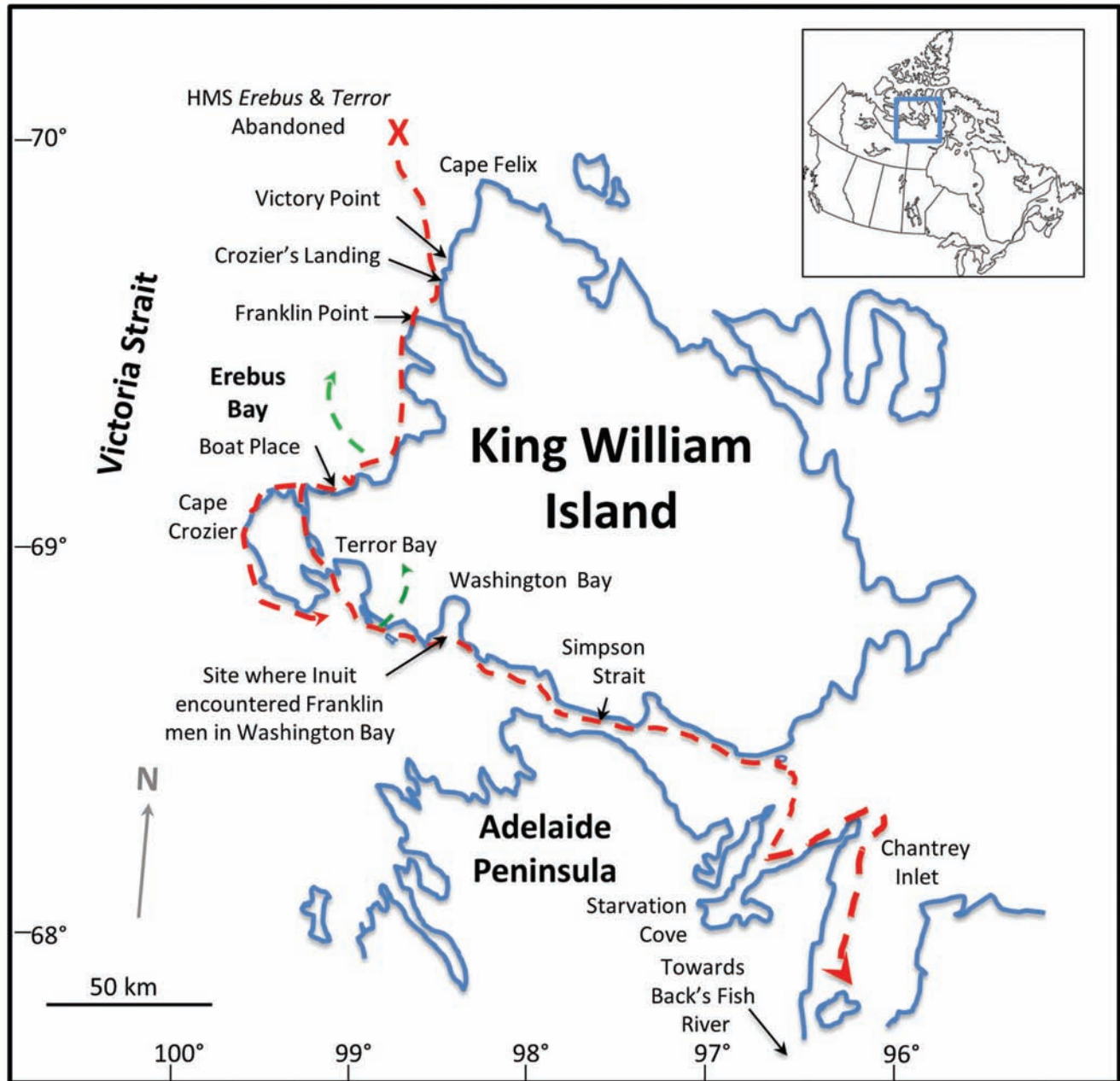


FIG. 1. Map of King William Island, Nunavut, showing the Franklin expedition's known and probable routes (red dashed line). Evidence also suggests that at least some of the crew attempted a return to the ships after an initial abandonment in 1848 (green dashed line).

the Admiralty to sponsor a series of search-and-rescue expeditions. Concern that the Admiralty expeditions were moving too slowly or searching in the wrong areas also prompted private individuals to mount their own expeditions. All told, nearly 40 ships searched the Canadian Arctic looking for the Franklin expedition. The enormous interest was fueled by a desire to recover survivors or the papers of the expedition. In 1850, it was learned that the expedition had overwintered in 1845–46 at Beechey Island, where three sailors had died (Beattie et al., 1992). In 1854, Dr. John Rae of the Hudson's Bay Company learned from Inuit testimony that the majority of the men had died of starvation along the shores of King William Island (KWI)

and west of the Back River (formerly the Great Fish River; Fig. 1) (Rae, 1889). Rae also reported that members of the expedition had likely resorted to cannibalism during their struggle for survival (M'Clure and Rae, 1854). The possibility of cannibalism resulted in widespread shock and anger in Britain and fueled further interest in what had happened.

It was not until Captain Francis Leopold McClintock and members of the *Fox Expedition* (1857–59) reached the shores of KWI that definitive news about the fate of Franklin and his crew was ascertained. From a note recovered at Victory Point, it was learned that the ships had become trapped in the ice of Victoria Strait northwest

of KWI in September 1846 (Fig. 1). An addendum to the record made in 1848 stated that Franklin had died in June 1847. Most critically, the Victory Point note reported that on 22 April 1848, the remaining 105 men of the original crew of 129 had deserted their ships. At Crozier's Landing, just south of Victory Point (Fig. 1), the crews came ashore and began to make final preparations for an overland march to reach the Back River (McClintock, 1860). No other written document has been found that shines additional light on the ultimate fate of the expedition.

As a result of the physical evidence and Inuit testimony, significant speculation has arisen as to what happened to the crew after they initially deserted their ships in April 1848. One of the most tantalizing firsthand reports was documented by Schwatka during his expedition of 1878 to 1880. Backed by the American Geographical Society, Lieutenant Fredrick G. Schwatka led a summer expedition to KWI to recover written records believed to have been previously overlooked. Schwatka learned that several Inuit families had encountered Franklin survivors on the ice (Schwatka, 1899; Woodman, 1991, 1995). The survivors were seen dragging several sledges laden with ship's boats on the southwest coast of KWI in Washington Bay (Fig. 1; online Appendix 1: Fig. S1). In fact, as summarized by Woodman (1991), three different narratives exist describing the encounter, each describing a different number of survivors (5, 10, and ~ 40), as well as different events and possible dates of the encounter (Nourse and Hall, 1879; Gilder, 1881; Schwatka, 1899). It was reported that many of the men were thin, and that "some of their mouths were hard and dry and black" (Gilder, 1881:91; Schwatka, 1899:36).

Many Franklin scholars believe from the description that the surviving crews were suffering from scurvy and possibly lead poisoning (Nourse and Hall, 1879; Beesly, 1881; Cyriax, 1939; Lamb, 1956; Kowal et al., 1989, 1991; Battersby, 2008). While scurvy and lead poisoning were likely contributors to the demise of the Franklin crew, the terms "hard and dry and black" are not pathognomonic for scurvy or lead poisoning. Therefore, to gain a deeper appreciation of what may have happened, we performed a systematic review of the medical literature to assess the oral conditions observed by the Inuit. From this analysis, we propose that in addition to scurvy or lead poisoning, military tuberculosis resulting in adrenal insufficiency (Addison's disease) may also have been the etiology for the conditions described. We hope this assessment will shed light on what has become one of the greatest mysteries of exploration.

## METHODS

Our searches were run in two stages. The first stage aimed to identify the possible etiology of black, hard, and dry mouth and involved searches in several databases and resources. We searched clinical point-of-care electronic resources Dynamed and UpToDate, as well as Google,

to identify possible causes of that oral condition. We supplemented those searches with targeted PubMed and Embase searches to retrieve citations published in health sciences journals that refer to black, hard, and dry mouth, as well as all citations that referred to the Franklin expedition in the citation title or abstract. In total, once duplicates were removed in Endnote X6, these searches retrieved 490 unique citations. Screening these citations confirmed that lead, scurvy, dental caries, coffee or tea, and tobacco were possible causes and also showed four additional possibilities: starvation, botulism, tuberculosis, and Addison's disease.

The second phase involved two components. First, we used broad searches to create large pools of citations for each of the nine possible causes (lead, scurvy, dental caries, coffee/tea, tobacco, starvation, botulism, tuberculosis, and Addison's disease) and then ran those against a set of all citations that refer to a black, hard, bleeding and dry oral condition. These searches were run in Ovid MEDLINE and Embase and resulted in an additional 1228 citations, which, when combined with the previous set of 490 citations, resulted in a total of 1718 unique citations. Preliminary searches were run during summer 2015. The formal, comprehensive searches were run during a three-month period (December 2015 to February 2016) and were limited to publications in English. All searches, with the exception of those targeting Franklin expedition studies, used both controlled terms and keywords (MeSH and Emtree). See Table 1 and online Appendix 1: Table S1 for a complete breakdown of the result numbers for each search. The complete search strategies are available in online Appendix 1: Table S2.

## RESULTS

Inuit encounters with Franklin crews can be classified into three main types: (1) face-to-face encounters with the Franklin crews or survivors, (2) encounters with solitary bodies or encampments with bodies, or (3) the discovery of relics or evidence of European activities (e.g., encampments, footprints) (Woodman, 1991, 1995). Direct encounters resulted in several references in the literature to the oral condition of the retreating Franklin crews. Schwatka related testimony of an Inuit woman named Ahlandnyuck who described the physical state of the survivors as "some of the men were very thin and worn out and their mouths were very dry, bleeding and black" (Schwatka and Stackpole, 1965:69–70). Others describe the condition as "dry and hard and black" (Gilder, 1881:91; Schwatka, 1899:36). While these descriptions do not allow for an accurate diagnosis, the fact that they refer to multiple crew members rather than a single individual suggests that a similar ailment was afflicting several members of the crew. On the basis of systematic searches, we considered the following nine ailments to be the most likely causes of the dry, hard, black oral condition: (1) botulism, (2) dental caries, (3) lead (4) scurvy, (5) starvation (6) tobacco,

TABLE 1. Total number of citations from Ovid MEDLINE and Embase when potential causes are crossed with hard, black, dry mouth.

Database	Hard, Black, Dry, Mouth and ...								
	Botulism	Caries	Lead	Scurvy	Starvation	Tobacco	Tea	TB	Addison's
Ovid MEDLINE	67	618	23	0	4	128	75	4	2
Embase	101	134	20	39	17	85	22	75	21
Total minus duplicates	103	685	26	39 <sup>1</sup>	19	191	73	73	19

<sup>1</sup> Includes results from preliminary searches in summer 2015.

(7) tea staining, (8) tuberculosis, and (9) Addison's disease (Table 2).

### Botulism

Botulism, a potentially fatal illness caused by botulinum toxin, has been hypothesized as a cause of illness for members of the Franklin expedition resulting from poorly preserved canned foods provided to the expedition (Horowitz, 2003). Using our search criteria, we identified 14 papers on botulism. The primary oral descriptors were dry mouth with or without difficulty swallowing (dysphagia), while intra- or extra-oral discolorations (e.g., “black”) or “hard” were not specifically mentioned.

### Dental Caries

The dental caries experience in many Native populations, including the Inuit, prior to Western contact has been reported to be rare (Costa, 1980; Keenleyside, 1998). Therefore, rampant and large, dark carious lesions would likely have been particularly noted by Inuit observers (Fig. 2B). We identified 685 papers on dental caries, of which three were relevant to our topic (Table 2). The first paper was a meta-analysis of a case-controlled population of individuals with severe mental illness in which significantly higher rates of decayed, missing, and filled teeth due to poor oral hygiene were identified (Kisely et al., 2015). The second paper reported that dementia is frequently associated with oral disease, including caries due to lack of oral hygiene, xerostomia, and periodontal disease, which can lead to pain and decreased oral intake (Foltyn, 2015). A third report focused on service personnel stationed in New Guinea during World War II experiencing a condition commonly known as “Jungle rot” (Bereston, 1942). Approximately 30% of the cases developed generalized violet maculopapular and nodular lesions. Nearly 5% of these cases demonstrated widespread extension of the pigmented areas. Together, these papers suggest that altered mental status or exposure to extreme environments may be associated with caries and “dry, hard, black” symptoms manifested in, or around, the oral cavity.

### Lead

The direct effects of lead on the oral cavity are well established. They include the discoloration of the gingiva,

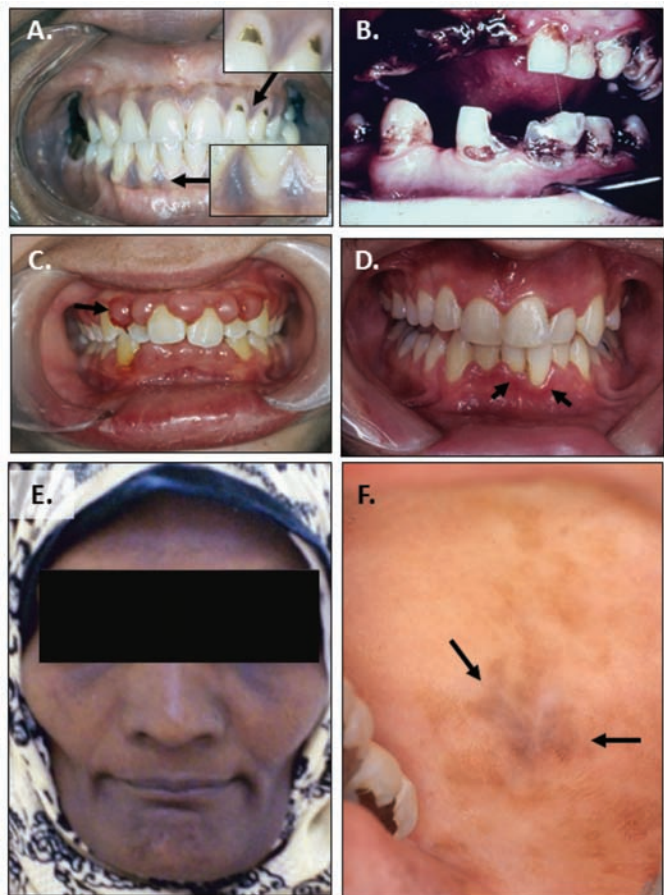


FIG. 2. Photographs of illustrative oral conditions: A) Demonstration of normal melanin deposition in a healthy individual (bottom insert). Top insert: Gold foil fillings similar to those reported by Hall for a skeleton recovered from KWI, originally attributed to Lieutenant Thomas Dundas Le Vesconte (HMS *Erebus*). Recent forensic facial reconstruction suggests the skeletal remains may have been those of Dr. Harry Goodsir, surgeon-naturalist of the Franklin expedition (Mays et al., 2011). B) Multiple sites of rampant dental caries. C) and D) Oral lesions associated with mild scurvy including inflamed gingiva and bleeding (C, arrow) and loss of tissue (D, arrows). E) Demonstration of extraoral melanosis in an individual with Addison's disease secondary to TB. Reproduced with permission (Al-Mamari et al., 2009). Note that the box covering the eyes has been darkened from the original figure. F) Melanosis of the cheek (arrows) in an individual with Addison's disease.

reductions in immune function and, progression of periodontal disease (Saraiva et al., 2007). Twenty-six reports were identified by the search strategy. The most pertinent report described chronic lead poisoning in 23 children intermittently exposed to lead fumes. A lead line in the gums and black deposits in the necks of teeth were found in 13 children. No extraoral symptoms were described (Joshua et al., 1974).

*Scurvy*

Scurvy, caused by a lack of dietary vitamin C, results in poor healing of wounds, including wounds to bone, cartilage, blood vessels, and the skin. Frequently, oral symptoms precede the general manifestations of the disease and include gingival hemorrhage, swelling, soreness, and extensive gingivitis often with purple appearance, loosening of the teeth, and halitosis (Holland, 1936; Hodges et al., 1969; Fig. 2C, D). Given sufficient time untreated, the condition may progress to tooth exfoliation. Eight reports were identified in the search strategy (Table 2), but none were relevant to the condition of the Franklin crew.

*Starvation*

Eating disorders (particularly regurgitation) and inadequate hygiene often affect the oral tissues. The systematic search focused on the terms “hard, dry, black” and “starvation” identified 19 new references (Table 2). None of these papers shed additional light on the oral symptoms observed for the Franklin crews.

*Tobacco*

Tobacco, chewing tobacco, alcohol consumption, and poor oral hygiene are often linked to oral staining. Tobacco was among the items supplied to the discovery ships, and significant supplies were in the ship’s boat discovered by McClintock in Erebus Bay (M’Clintock, 1860). We identified 191 reports that met the search criteria for “dry, hard, black” and “tobacco” (Table 2). None of these reports specifically can be linked to the “dry, hard, black” descriptors even when dental calculus or tobacco staining was considered. Most germane to our investigation were two reports that described methods for assessing oral melanosis in different populations and a case study that described the condition known as black hairy tongue (Khasawneh et al., 2013).

*Tea*

Tea represented a major supply taken aboard the discovery vessels. Seventy-three references were identified by crossing the terms “tea” and “dry, hard, black.” The majority of these papers focused on physiologic processes activated by components of tea, or the staining of teeth or restorations (Table 2). Three papers focused on the erosive effects of tea on tooth structure or tea components as a cancer preventive, or were not relevant.

*Tuberculosis*

*Mycobacterium tuberculosis* (TB) infections represent a serious communicable disease that is widespread and often presents with life-threatening consequences resulting from pulmonary failure. In the beginning of the 21st century,

TABLE 2. Citations when potential causes are crossed with hard, black, dry mouth.

Topic	Content	Number	
Botulism	Dental care	1	
	Food-borne botulism	14	
	Salivation	12	
	Not relevant	76	
	<b>Subtotal</b>	<b>103</b>	
Dental caries	Cancer treatment	26	
	Caries treatment	107	
	Development	50	
	Diagnosis	40	
	Epidemiology	31	
	Etiology	53	
	Genetic	5	
	Iatrogenic	4	
	Microorganisms	45	
	Xerostomia	54	
	Relevant	3	
	Not relevant	267	
	<b>Subtotal</b>	<b>685</b>	
Lead	Exposure	4	
	Lead line	1	
	Tooth loss	1	
	Not relevant	20	
	<b>Subtotal</b>	<b>26</b>	
Scurvy	Animal models	2	
	History	14	
	Oral condition	8	
	Not relevant	15	
	<b>Subtotal</b>	<b>39</b>	
Starvation	AIDS	1	
	Animal studies	2	
	Histologic investigations	10	
	Refeeding	3	
	Vascular malformations	3	
	<b>Subtotal</b>	<b>19</b>	
	Tobacco	Cancer therapy/care	9
Epidemiology		52	
Etiology		42	
Histologic or diagnostic		40	
Microbiology		1	
Oral Health Quality of Life (OHQoL)		2	
Staining		18	
Systemic effects		14	
Tissue physiology		10	
Tobacco melanosis		3	
<b>Subtotal</b>		<b>191</b>	
Tea		Oral Health	2
		Physiology	20
	Staining	20	
	Treatment	23	
	Not relevant	8	
	<b>Subtotal</b>	<b>73</b>	
Tuberculosis	Perioral findings	4	
	Review article	2	
	TB Cases	41	
	Not relevant	26	
	<b>Subtotal</b>	<b>73</b>	
Addison’s disease	Hyperpigmentation	2	
	Review paper	3	
	Not relevant	14	
	<b>Subtotal</b>	<b>19</b>	
<b>Total</b>		<b>1228</b>	

oral lesions were seen in 0.05% to 5.0% of patients with TB (Kakisi et al., 2010; Kamala et al., 2011). In our survey, 73 reports were identified, of which 41 were case reports, four were epidemiologic investigations, and two were review articles. On closer inspection, the remaining 26 reports

were not relevant since TB was evaluated but ruled out as a candidate for a reported condition (Table 2). Among the case reports, 20% mention oral or perioral discolorations as prominent features of the subjects. While dry mouth (xerostomia) was a prominent feature of all of the cases, 17% describe swollen parotid glands associated with dry mouth. In the epidemiologic studies, extraoral lesions with dark discoloration features were reported, as well as mucosal lesions of the mouth and pharynx described as stippled or uniform dark red or bluish lesions, particularly of the gums (Kakisi et al., 2010).

### *Addison's Disease*

Adrenal insufficiency or Addison's disease occurs when the adrenal glands fail to produce sufficient levels of cortisol. Currently in the United States, autoimmune disorders affecting the endocrine system are the primary cause of Addison's disease. Worldwide, tuberculosis remains the predominant cause of Addison's disease and accounts for 10% to 15% of Addison's disease cases in developed countries (Arlt and Allolio, 2003; Nieman, 2013). Surprisingly, in those case reports that described patients with oral or perioral discolorations, 38% report Addison's disease as a feature (Fig. 2E, F). Further searches of "dry, hard, black" and "Addison's disease" identified 19 papers, of which 17 were either review papers or excluded Addison's disease as a diagnosis (Table 2). The two remaining references both described weakening, hyperpigmentation, and dry mouth associated with adrenal insufficiency.

## DISCUSSION

The fate of the Franklin expedition has been shrouded in mystery. To gain further insight into what may have contributed to the demise of the surviving Franklin crews, we performed a systematic review of the medical literature focused on symptoms reported by Inuit observers. The Inuit testimony regarding the physical state of the crewmen comes from the narrative reports by Hall (Nourse and Hall, 1879) and Schwatka (1899) and from Gilder's (1881) summary of the latter's expedition. Each of these three narratives describes a different number of survivors (5, 10, and ~ 40, respectively, as summarized by Woodman, 1991). While it is likely that the exact number of individuals afflicted by the condition will never be known, the term "some of the men" suggests that a sufficient number of individuals were involved to attract notice.

Many scholars of the Franklin Search believe that the poor physical and oral conditions of the surviving crew were due to scurvy. Indeed, Arctic mariners were susceptible to scurvy for lack of the Vitamin C provided by fresh fruit, vegetables, and fresh meat. Humans depend on the dietary intake of Vitamin C: we are unable to convert L-gluconamylactone to L-ascorbic acid, as other animals can do, because we lack the enzyme

L-gulonolactone oxidase (Kim et al., 2012). The most notable manifestation of scurvy results from poor healing of wounds, including wounds in bone, cartilage, blood vessels, and skin. Typical oral findings include loosening teeth and inflamed, pus-filled, and puffy gingiva that make eating painful. In addition, a foul odor (halitosis) is often used to describe the oral cavity of those suffering from scurvy.

It is likely that some of the surviving members of the Franklin expedition were suffering from scurvy at the time of their encounter with Inuit in Washington Bay. The clinical signs of scurvy do loosely match the description of men whose "mouths were hard and dry and black." However, a recent examination of 105 bones of the Franklin crew, representing at least four sites where the crew perished, noted few pathologic changes attributable to scurvy (Mays et al., 2015). Given the limited sample size, these findings might not be representative of the main body of the crew (Mays et al., 2015). Indeed, an earlier study of some of the crew's remains did identify signs of scurvy (Beattie and Savelle, 1983), as did a recent evaluation of Royal Naval Arctic crews involved in the search for Franklin (Millar et al., 2016). These observations, while suggestive that scurvy may have had a role in the poor oral condition of the Franklin crews, do not rule out other causes worth investigating.

Lead poisoning has also been proposed as a major factor in the demise of the Franklin expedition (Kowal et al., 1989, 1991; Keenleyside et al., 1996). Lead is a neurotoxin, resulting in cognitive and behavioral defects; confusion, muscle weakness, stumbling, aggressive behavior, irritability, fatigue, and memory loss are all signs of lead exposure. Two potential sources of lead may have contributed to the crew's exposure; lead solder used to seal the canned food, or lead in the piping used to distill water to make it potable (Keenleyside et al., 1996; Brown and Margolis, 2012; Millar et al., 2015). Speculation that the men suffered from cognitive impairment has come from the fact that the Victory Point note, recovered by M'Clintock, suggests that Fitzjames recorded the wrong year that the expedition overwintered at Beechey Island. The gravestones at Beechey Island indicated that the expedition overwintered there in 1845–46, but Fitzjames recorded the overwintering dates as 1846–47. A second line of "evidence" suggesting that the crews were suffering from an altered mental state was M'Clintock's observation of substantial stores of heavy and conceivably useless items at Crozier's Landing and at the Boat Place in Erebus Bay (M'Clintock, 1860). Together, date confusion and heavy materials taken on the overland march have fueled conjecture that the crews were making poor decisions, although this point has been disputed (Woodman, 1991; Millar et al., 2016). More recently, attention was drawn to lead poisoning after autopsy and forensic analyses identified high lead levels in the tissues of the Franklin men (Kowal et al., 1989, 1991; Keenleyside et al., 1996; Battersby, 2008); however, since contemporary European

control samples were not included in the analysis, it remains unclear whether the lead levels were unusual for the era.

In addition to cognitive and behavioral effects, lead poisoning has significant effects on the oral cavity, bone, mucosal tissue metabolism, and the immune system. Using data from the Third National Health and Nutrition Examination Survey (1988–94), Saraiva et al. (2007) analyzed 2500 men and 2399 women, ages 20–56, who had received complete periodontal examinations and found blood lead levels were associated with periodontitis for both men and women. Similarly, a study of workers chronically exposed to lead fumes and dust in a storage battery plant in Alexandria, Egypt (El-Said et al., 2008), demonstrated that exposed workers had increases in the prevalence of gingivitis, periodontitis, and caries. Experimentally, primates exposed to lead lost weight and developed profound anemia and thin, grey-blue lead lines visible along the gingival margins (Zook et al., 1976). Chronic lead exposure also resulted in the formation of chapping of the angles of the mouth (cheilitis), fissures, ulcers, and epithelial desquamation of the tongue, palate, and other parts of the oral mucous membranes (Zook et al., 1976). Yet despite the clear linkages between lead and oral symptoms, our systematic review failed to identify lead exposure as a likely sole source of the symptoms recorded during the encounter of Inuit with Franklin crew members in Washington Bay.

Rampant dental caries was also investigated as a source of the Inuit testimony pertaining to “black” in the mouths. Cariogenic materials such as sugar, rum, and chocolate were among the expedition’s supplies, and McClintock found 40 pounds of chocolate in a ship’s boat discovered in Erebus Bay (McClintock, 1860). While black stains are frequently attributed to individuals with rampant caries and are characterized as dark lines or dark spots on the teeth (Fig. 2B), our literature review found that non-developmental tooth discoloration, in particular black stains, are frequently associated with a lower caries experience, at least in children (Garan et al., 2012). Importantly, dental caries was an unusual feature in the indigenous populations prior to the introduction of processed foods, suggesting that Inuit observers would certainly have noted obvious black markings of dental decay (Costa, 1980; Keenleyside, 1998). It is important to note, however, that carious lesions are not a prominent feature of the limited skeletal remains of the Franklin crews recovered in Erebus Bay (A. Keenleyside, pers. comm. 2015). Likewise, our search also did not identify dental caries or black stains as significant features worthy of further investigation. Similarly, botulism, starvation, tea, and tobacco use were also terms that arose as possible etiologies to describe thin sailors with mouths that are dry, hard, and black. Nevertheless, the possibility remains that these conditions may have contributed to what was observed.

From our literature review, tuberculosis (TB) was identified as a possible etiology for the symptoms described by the Inuit. For multiple individuals to be suffering from a

similar condition suggests an infectious disease as a prime etiologic candidate, although toxins and dietary deficiencies are also possibilities. At the time of the expedition, TB was a major cause of death in Europe, accounting for as many as one in seven deaths (Koch, 1882; Wilson, 2005). Indeed, shipborne outbreaks of respiratory diseases, including TB, were common in the 1840s and continue well into the present day (Bayliss, 2002; Davies and Yew, 2003; Ono et al., 2003; Hansen et al., 2006; Ongre and Sommerfelt-Pettersen, 2008). The primary manifestations of a TB infection in the oral cavity have been reported as single, rather than multiple, ulcers (55%), with “indurated, ill-defined margins and a hard necrotic base (58%) or covered with greyish or yellow slough (42%)” (Kakisi et al., 2010:105). In addition, pain while eating is a most common symptom. Difficulty speaking, burning sensations, reflux, halitosis, and intra-oral bleeding were also noted (Kakisi et al., 2010). While the Inuit reported that they had difficulty understanding the Franklin survivors, it is unclear whether they could have distinguished between a strong language barrier and a crew member’s pain-induced speech pattern. It is of significant interest that many of the reports identified by our search suggest that oral or perioral discolorations are prominent features of TB. Importantly, xerostomia or “dry mouth” was a feature of all of the cases, and 17% of the reports describe swollen parotid glands. Extraoral lesions with dark discoloration features were reported in the epidemiologic studies. Surprisingly, 38% of the cases report adrenal insufficiency, or Addison’s disease, as sequelae or as features of TB when oral or perioral discolorations were present.

So what happened to the Franklin survivors? Infectious diseases, toxins, and dietary deficiencies are all possible ailments that could have affected multiple crew members. We believe that the most compelling evidence as to what happened can be gleaned first in the autopsies performed on the bodies buried at Beechey Island. Each of these men showed evidence of pulmonary TB, and in some cases miliary TB, the form of the disease that spreads to distant organs (Notman et al., 1987; Notman and Beattie, 1996). The adrenal glands are a major target of TB (Nieman, 2013). Thomas Addison first described this condition as bilateral adrenal destruction in 1855. In the 1800s, TB was the most common cause of Addison’s disease (Nieman, 2013). TB under conditions of vitamin C deficiency and elevated lead levels becomes more virulent and theoretically is more likely to spread from the pulmonary system (Troesken, 2006; Taneja et al., 2010; Vilchère et al., 2013). In addition to weakness and fatigue, hyperpigmentation and diffuse tanning of exposed surfaces are reported for Addison’s disease (Nieman, 2013). Black freckles of the face, forehead, and neck and bluish-black discolorations of the lips and mouth are noted at later stages of the disease and may reflect the Inuit observation of “black” (Mariette, 1975; Lamey et al., 1985; Kim, 1988; Erickson et al., 2000; Sarkar et al., 2012). Anorexia, nausea, and diarrhea also often occur, along with diminished cold tolerance (Nieman, 2013),

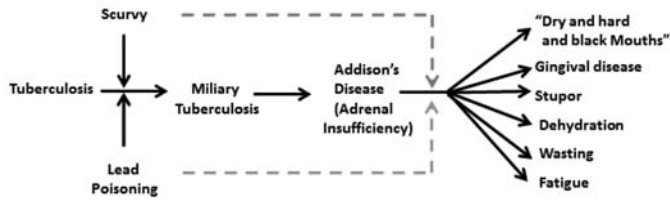


FIG. 3. Hypothesis model for the oral condition of the Franklin crew. Our model suggests that tuberculosis in conjunction with scurvy and lead poisoning resulted in miliary tuberculosis, leading to adrenal insufficiency or Addison's disease. Addison's disease symptoms include "dry and hard and black" mouths, stupor, dehydration, wasting, and fatigue.

as does dizziness and syncope, weight loss, dehydration due to alterations in sodium reabsorption and potassium excretion, and hypotension—all are characteristic of the terminal stages of Addison disease (Nieman, 2013). This combination of symptoms may have been described by the term "thin men" or the observation "dry." Thus, some of these features are consistent with the symptoms ascribed to some of the Franklin crew and represent a plausible clinical course during a forced survival march (Fig. 3).

Is there any evidence for the tuberculosis-Addison's hypothesis? We know that three members of the Franklin crew buried in 1846 at Beechey Island had evidence of TB exposure (Notman et al., 1987; Notman and Beattie, 1996). The expedition then sailed towards KWI and at some later point became icebound. Hall (cited in Woodman, 1991:205) recorded a story related to him by the Inuit, which is often referred to as the "Black Men" story. These "Black Men" are suspected to have been coal stokers on board the ships and may have frightened the Inuit who visited the ships. During the "Black Men" visit, the Inuit met a high-ranking officer who pointed to a spot on the land where a large tent was pitched. The officer asked the Inuit if they saw the tent, whereupon the "Captain" told the Inuit that "Black" men lived there and no one must ever go there (Woodman, 1991). Later, Captain Peter Bayne, an employee hired by Charles Hall during his search for the Franklin expedition, also reported Inuit testimony that the large tent was filled with many sick men (Burwash, 1931). We believe it is very possible that this tent represented a shore-based hospital intended to isolate and treat the TB consumptive crews in keeping with the fresh-air TB treatments of the time (Dormandy, 2000). There are, of course, other explanations for the tent story. Woodman (1991) suggested that the tent might have been the cache for the ships' gunpowder supplies (these were routinely stored at a distance from Royal Naval ships for safety reasons) or that the tent could have been occupied by men who were practicing cannibalism. Whether the tent represented a cache of gunpowder, a collapse of discipline resulting in cannibalism, or a hospital for the TB-afflicted crew members cannot be known unless the tent site is identified and subjected to archaeological investigation or was recorded in an expedition record that has yet to be located.

Other evidence for the tuberculosis-Addison's hypothesis may come from the Victory Point note, which indicated

that nine officers and 15 men had died by 1848 and that the surviving 105 of the original 129 men had abandoned their ships (M'Clintock, 1860). It has been surmised that a disproportionate number of officers versus crew had died. A correlation between age and rates of mortality due to TB has been observed in many settings, which suggests that the older officers would have been disproportionately affected (Frost, 1995; Woods and Shelton, 1997; Pérez-Guzmán et al., 1999), although the idea that the death rates of the officers and the non-officer ranks on Franklin's ships had an unusual relationship has also been disputed (Millar et al., 2016).

Recently, Christensen et al. (2016) reported that John Hartnell, one of three Franklin expedition members buried on Beechey Island, was chronically zinc-deficient. Zinc deficiency is well established as a cause of immunosuppression, which in combination with tuberculosis may have resulted in Addison's disease (McMurray et al., 1990).

Why did the crew abandon their ships, and why were the deaths of the officers disproportionate to those of the crew? Inuit testimony suggests that at least one of the ships was reboarded and sailed farther from where the ships were first abandoned, which indicates that at least one of the ships was structurally sound (Woodman, 1991). A plausible explanation for why a mariner would abandon a sound ship could be the presence of a contagious disease. While there are many compelling reasons why the Franklin crews may have abandoned their ships, we believe that a severe outbreak of TB may have led to the abandonment of the ships in April of 1848 and may explain why the death rate among the officers was higher than expected.

Is there further evidence that a contagious disease was at least in part the reason why the crews abandoned their ships? At the time of the ships' abandonment, the most direct place for the crew to come ashore while traveling in a southerly direction would have been Franklin Point. Yet the mariners detoured east to what has come to be known as Crozier's Landing near Victory Point, bringing with them four heavy cast-iron ship's stoves and kettles. They also abandoned a pile of clothing reported to be four feet high (M'Clintock, 1860). Additionally, part of an oar sawed longitudinally with a blanket nailed to its flat side was found, as well as a hollow brass curtain rod three quarters of an inch in diameter (M'Clintock, 1860). We hypothesize that the crews purposely came ashore near a large freshwater lake (Cooper's Lake east of Crozier's Landing) at Victory Point to bathe and abandon their infected clothing prior to beginning their trek towards Back's Fish River. The oar, the blanket, and the iron curtain rod may have been used to construct a bath house, and the large kettles, to heat bathing water.

The tuberculosis-Addison's theory is not without its difficulties. Scurvy, a condition frequently associated with oral bleeding, was a common condition experienced by Arctic exploration crews during the 19th century (Millar et al., 2016). Perioral bleeding is frequently described as



TABLE 3. Citations for dry and hard and black mouth.

Year reported	Oral condition described	Inuit observer	References
1881	“Some of the white men were very thin, and their mouths were dry and hard and black.”	Ahlangyah	(Gilder, 1881:91)
1881	None	Alañnak	(Klutschak, 1881)
1899	“The white men, said Ahlangyah, were without fur clothing; some of them were very thin, and their mouths were hard and dry and black.”	Ahlangyah	(Schwatka, 1889:36)
1965	“They looked thin and worn out and their mouths were dry, bleeding and black.”	Ahlandnyuck	(Schwatka and Stackpole, 1965:69–70)
1987	None	Alañnak	(Barr, 1987)
1991	“Some of the white men were very thin, and their mouths were dry and hard and black.”	Ahlangyah	(Woodman, 1991:134)

having “black” coloration, particularly when dried, and may also present as “hard.” Both Hall during his second expedition (1864–69; Nourse and Hall, 1879) and members of the Schwatka expedition (Gilder, 1881; Klutschak, 1881; Schwatka, 1899) reported interviews with Natives who had encountered Franklin expedition survivors (Table 3). Unfortunately, the authors have been unable to locate the original notes taken by either Schwatka or Gilder on their 1864–69 expedition. In 1965, however, Stackpole published what appears to have been an early draft of the Schwatka book, but in this case the oral conditions were stated to be “dry and bloody and black” (Schwatka and Stackpole, 1965:69–70; online Appendix 1: Fig. S2). The inclusion of the term “bloody” along with “black” in Schwatka’s description may represent the oral symptoms of scurvy. In fact, Nourse, Hall’s biographer, believed that the Franklin crews were suffering from scurvy, but makes no specific mention of the oral condition of the survivors except to describe a gold foil restoration in one of the skeletons recovered by Hall from KWI (similar to the gold restorations presented in Fig. 2A) (Nourse and Hall, 1879). Hall’s KWI traveling journal No. 38 (online Appendix 1: Fig. S3) and Nourse’s book describe gingival conditions consistent with scurvy among the bodies found at Starvation Cove (Nourse and Hall, 1879).

Finally, another possibility that could result in a dry oral cavity but was not identified by our search is dehydration. Water supplies were notoriously limited on ships of this era and were likely contaminated with bacteria or by seawater. Further, while on land, or while dragging ship’s boats on the ice, potable water may also have been limited in supply, particularly if fresh water had to be made by melting ice when fuel was limited. If this were the case, one would wonder why only “some of the men” would have had the oral condition described, and why the Inuit would have specifically noted this condition, as surely they too had experienced dehydration.

A limitation of our approach is the use of current medical databases to investigate diseases that occurred in the 1840s, when the pattern and severity of diseases were likely different from those seen today. For example, rates of TB, scurvy, and other conditions are known to have changed over time (Cook, 2004; Daniel, 2006). Similarly, tobacco use and oral hygiene methods have changed since

the 1840s. Therefore, the relative absence of a condition in the current medical literature does not necessarily rule out an etiology for a condition described by the Inuit at that time.

Sometime after leaving Crozier’s Landing, the retreating crews were observed by Inuit in Washington Bay. From that juncture, it is highly likely that significant mortality ensued. In an inlet on the mainland not far from King William Island, called “Starvation Cove,” the last of the party died (Woodman, 1991). The Inuit reported seeing significant stores of canned food that were “sweet and good,” yet the white men were very thin (Nourse and Hall, 1879:606). Here, too, we believe that miliary TB targeting the adrenal gland may have been partially culpable. As described previously, the adrenal gland regulates sodium uptake in such a way that one can become dehydrated during adrenal insufficiency. And perhaps most critically, during the ensuing metabolic dysregulation, victims are unable to maintain weight in the face of plentiful food sources (Nieman, 2013).

In conclusion, using a systematic review to critically assess the oral conditions of members of the crew of the Franklin expedition, we have identified a new and plausible explanation for the wasting and oral conditions of some of the crew members. Our hypothesis implicating a tuberculosis-Addison’s disease axis explains well the limited physical evidence and Inuit testimony as to what happened to the crew after they abandoned their ships in April 1848. The hypothesis accommodates the possibility that scurvy, an ascorbic acid deficiency, as well as lead poisoning, could have contributed to the pathogenesis of the disease, but it is not wholly dependent on these conditions, which have been in dispute (Kowal et al., 1991; Bayliss, 2002; Mays et al., 2015). Our work builds on prior investigations of the Franklin expedition, but also reveals a new and perhaps deeper understanding of the fate of Franklin and his crew.

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#### APPENDIX 1

The following tables and figures are available in a supplementary file to the online version of this article at:

<http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/rt/supfiles/4629/0>

TABLE S1. Initial searches to define search terms.

TABLE S2. First and second phases of the literature search.

FIG. S1. Washington Bay, site of the Franklin crew/Inuit encounter, photographed from ~183 m (~600 feet) above sea level on 8 August 2015. (A) Direction of photograph is the head of the bay from the southeast looking northwest. (B) Direction of the photograph is from the south looking north.

FIG. S2. Image from Schwatka's journal describing the oral conditions of the Franklin crew in Washington Bay, King William Island, Nunavut. "They looked thin and worn out and their mouths were very dry bleeding & black. They were all wearing white men's clothing." Misc. Vol 163, Manuscripts Collection, G.W. Blunt White Library, Mystic Seaport Museum, Inc., Mystic, Connecticut.

FIG. S3. Image from Hall's King William Island traveling journal #28, which describes the oral conditions of the Franklin crew. "One man a very short man. One man very fat all over – one man with a single upper front tooth gone. One man with very large bleeding gums – lower gums." Charles Francis Hall Collection, Archives Center, National Museum of American History, Washington, D.C.

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