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Thomas A. Crist

Marcella H. Sorg

University of Maine, mhsorg@maine.edu

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Adult scurvy in New France: Samuel de Champlain's "Mal de la terre" at Saint Croix Island, 1604–1605

Q1 Thomas A. Crist^{a,*}, Marcella H. Sorg^{b,1}

^a Programs in Physical Therapy and Sociology/Anthropology, Utica College, 1600 Burrstone Road, Utica, NY 13502, USA

^b Department of Anthropology, University of Maine, 5773 South Stevens Hall, Orono, ME 04469-5773, USA

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"Scurvy was responsible for more deaths at sea than storms, shipwreck, combat, and all other diseases combined."

Scurvy, Stephen R. Bown (2003:3).

1. Introduction

Scurvy, long the scourge of sailors, results from a prolonged deficiency of dietary ascorbic acid (the reduced form of vitamin C) or the inability to metabolize adequate amounts of the vitamin. The clinical manifestations of severe vitamin C deficiency (avitaminosis) arise because unlike most other mammals, humans are unable to synthesize ascorbic acid and must maintain its regular intake, mainly from fruits and vegetables. Consequently, the disorder reflects a complex combination of human physiology, socioeconomic factors, and environmental conditions (Bown, 2003; Carpenter, 1986; Cheung et al., 2003; Strayer and Rubin, 2012), such that anthropologists have interpreted its prevalence as an indicator of social or environmental stress (e.g., Geber and Murphy, 2012; Ortner et al., 1999, 2001).

Because of the difficulties in accurately identifying nutritional deficiencies among human remains from populations where significant malnutrition was known to have existed, numerous authors have noted that scurvy is particularly underreported (Aufderheide

and Rodríguez-Martin, 1998; Brickley and Ives, 2008; Ortner, 2003). The vast majority of paleopathological research that does address scurvy involves infants and children (e.g., Brickley and Ives, 2006; Brown and Ortner, 2011; Mays, 2008; Melikian and Waldron, 2003; Ortner and Ericksen, 1997; Ortner et al., 1999, 2001). This owes much to subadult ontogeny being more sensitive than adult biology to environmental and socioeconomic stressors (Goodman and Armelagos, 1989; Lewis, 2007) and the hemorrhagic effects of scurvy are more pronounced on developing bones. In adults, clinical symptoms take months to appear and gross skeletal lesions are often not visible (Brickley and Ives, 2008; Ortner, 2003).

Maat (1981, 1984a, 1984b) conducted the first in-depth study of adult scurvy using an archeological skeletal sample of 50 men found in a late seventeenth-century Dutch whalers' cemetery at Spitsbergen, an archipelago located about 600 miles north of Norway. He concluded that scurvy was the most likely cause for the high prevalence of black maculae (stains) that were present on the articular surfaces of the lower limb joints (hemarthrosis) in virtually all of the individuals available for study. Based on the distribution of ossified subperiosteal hematomas among the lower limb bones and coincident periodontal disease, Van der Merwe et al. (2009, 2010a, 2010b) diagnosed scurvy in 16 adults from a site in Kimberley, South Africa where over 100 migrant mine workers had been buried between ca. 1897 and 1900. Most recently, Geber and Murphy (2012) documented similar lesions in their diagnosis of scurvy among 425 adults from the mid-nineteenth-century Kilkenny Union Workhouse burial ground in Ireland.

This paper describes the pathological lesions observed among the incomplete skeletal remains of 20 men who accompanied

* Corresponding author. Tel.: +1 315 793 3390.

E-mail addresses: TCrist@utica.edu (T.A. Crist), Marcella.Sorg@umit.maine.edu (M.H. Sorg).

¹ Tel.: +1 207 581 2596.

Samuel de Champlain to colonize New France and died at Saint Croix Island, Maine, during the winter of 1604–1605. Their graves were excavated in 1969 and again in 2003 on this six-acre island located in the middle of the Saint Croix River, which serves as the border between the U.S. and Canada. Champlain's documentation of the symptoms of the afflicted, which he called "*mal de la terre* (land sickness), otherwise scurbut" (Champlain, 1922 [1613]:303) represents the only known case in the historical literature in which an eyewitness account of the suspected disorder is available to accompany the paleopathological analysis of recovered bones. The purpose of this analysis is to test whether skeletal lesions potentially consistent with scurvy indeed existed among the remains of these men. The results also address the questions: (1) did Champlain correctly recognize the disorder and (2) how did these Renaissance-period colonists attempt to treat scurvy at their early settlements in New France?

2. Clinical symptoms and paleopathology of adult scurvy

In both adults and children, the clinical symptoms and skeletal lesions associated with scurvy result from defective collagen formation in normal connective tissue and small hemorrhages or "leaking" of blood through the voids in the walls of arteries and veins (Cahill and El-Sohemy, 2009; Garcia et al., 2012). Ascorbic acid is a critical component in biosynthesis of collagen, serving as the "cement" that binds together the connective tissues. Prolonged deficiency of dietary ascorbic acid, genetic anomalies, and other disease processes also depress the normal osteogenic activity of osteoblasts in otherwise normal bone tissue, reducing and finally halting the formation of new bone.

Scurvy is clinically recognized in adults through its hemorrhagic manifestations, especially bleeding gingiva, ecchymoses due to bleeding into the subcutaneous tissues, hemarthrosis, and perifollicular petechiae (Lau et al., 2009; Strayer and Rubin, 2012). In many victims, the gums become so swollen and blackened that teeth are obscured. Secondary infections arise from inadequate dental hygiene as inflammation spreads across the mucosal tissues that cover the hard and soft palates and the gums. Teeth become loosened as inflammation drives resorption of alveolar sockets, allowing especially the anterior single-rooted teeth to exfoliate. Wound healing ceases, and anemia may result from bleeding and impaired iron absorption.

Most previous paleopathological descriptions of scurvy are based on the skeletal remains of infants and children (Aufderheide and Rodríguez-Martin, 1998; Ortner, 2003; Steinbock, 1976; Zimmerman and Kelley, 1982). The most prominent lesions reflect healed or active but prolonged incidents of scurvy. These can include organized subperiosteal hematomas among the lower limb bones, deposition of abnormal new bone in areas of biomechanical stress, and pathological porosity at locations where chronic bleeding causes localized periosteal inflammation (Brickley and Ives, 2006; Brown and Ortner, 2011; Geber and Murphy, 2012; Ortner, 2003; Ortner et al., 1999, 2001; Van der Merwe et al., 2010a,b). Geber and Murphy (2012) demonstrate statistically significant relationships between porotic lesions on the maxilla, mandible, and the sphenoid bone. Scorbutic lesions among adults are reportedly similar in their appearance and distribution although diminished in their severity, with more noticeable involvement of the alveolar bone and dentition.

Until recently, diagnosis of adult scurvy was largely based solely on the presence of periosteal lesions among the lower limb bones (e.g., Cybulski, 1988; Rose and Hartnady, 1991; Williams, 1994). Some researchers did identify excessive antemortem tooth loss without other periodontal lesions as reflective of scurvy (e.g. Holck, 1984; Saul, 1972); Wells (1964) and Živanović (1982) suggested

that periosteal lesions of the hard palate and alveolar processes also may be indicators of scurvy in adults. Molleson and Cox (1993:153) suggested that "pitting of the palate" or "porotic palate" among several subadults recovered from the crypt at Christ Church in Spitalfields (ca. 1729–1852) was indicative of mild scurvy. Similarly, Crist (1998) suggested a linkage between maxillary and mandibular lesions with the soft tissue manifestations of scurvy when analyzing the remains excavated in 1969 from Saint Croix Island.

Vitamin deficiencies also have been associated with the formation of palatine tori on the hard palate (García-García et al., 2010); Živanović (1982) specifically links formation of the feature to scurvy. A palatine torus is a bony protuberance of varying form that is situated along the median suture where the left and right maxilla and palatine bones articulate. Usually identified as a non-metric trait of genetic origin (Hauser and De Stefano, 1989), the high frequency of its expression among medieval northern Europeans has been interpreted to reflect increased masticatory stress and malnutrition (Halfman et al., 1992). Singh (2010) proposed that the formation of palatine tori may be the result of repetitive, compressive stress from pathological chewing activities focused along the patent median suture, triggering an osteogenic periosteal response. If palatine tori are in fact associated with malnutrition, it is currently unclear what the minimum duration of the deficiency must be for their development.

Brickley and Ives (2008) provide criteria that they argue are diagnostic of adult scurvy, specifically, new bone formation in the orbits and long bones and transverse rib fractures. They did not include either abnormal porosity of the cranial bones where the muscles of mastication attach or the formation of palatine tori. Recognizing that skeletal remains from archeological sites are often incomplete or poorly preserved, Geber and Murphy (2012) offer a three-level classification system (definite, probable, and possible) for diagnosing scurvy based on the co-occurrence of lesions that they identified among the skeletons of 425 adults and 545 children under 18 years old buried between 1847 and 1851 at the Kilkenny Union Workhouse. A definite diagnosis was based on the coincident presence of porous lesions of the sphenoid bone, maxillae, and mandible, new bone formation on the long bones, and the presence of bilateral subperiosteal lesions. They further noted that porosity of the lesser wing of the sphenoid bones, endocranial lesions of the parietal bones and hyperostosis at the infraorbital foramina are all suggestive of scurvy. These authors did not address antemortem tooth loss or the presence of palatine tori as potential scorbutic indicators.

3. Materials and methods

3.1. Contemporaneous documentation of the mass fatality event and archeological context

Beginning in the early 1500s, French ships regularly visited the coast and inland waterways of modern-day Canada and New England (See, 2001). In 1603, King Henri IV granted the fur monopoly in New France to a Huguenot nobleman named Pierre du Gua, Sieur de Monts, in return for the transport of 100 colonists every year to the New World. Du Gua led his first colonizing expedition in 1604 to a tiny island that he named Saint Croix, employing Samuel de Champlain (1567–1635) as his geographer and mapmaker. Champlain kept a journal documenting their experiences (Champlain, 1922 [1613]).

Comprising a group of 79 French gentlemen, skilled artisans, laborers, soldiers, clergymen, and at least two surgeons, the settlers arrived at Saint Croix Island in June 1604 after a three-month trans-Atlantic voyage. By winter, they found themselves stranded at their settlement in the middle of the frozen Saint Croix River. According

to Champlain's journal, snow fell constantly from October to April. Over the winter the men subsisted on Spanish wine, frozen cider, melted snow, and "salt meat and vegetables" (Champlain, 1922 [1613]: 306–307). Champlain reported that 35 men died during that winter and were buried on the island. Ascribing all of their deaths to scurvy, he detailed the affected men's symptoms (Champlain, 1922 [1613]: 303–306).

Archeological excavations for the U.S. National Park Service in the 1950s revealed the location of the cemetery (Hadlock, 1950; Harrington and Hadlock, 1951). More extensive excavations in 1969 identified 23 individuals in the cemetery (Gruber, 1970). Gruber's team removed the best-preserved bones and teeth to Temple University in Philadelphia where they were later studied in greater detail (Crist, 1995, 1998). Excavations in 2003 to rebury the remains revealed two more graves and provided an opportunity to systematically examine each individual's skeleton *in situ* (Crist et al., 2012; Crist and Sorg, 2004; Pendery, 2012).

3.2. Scurvy in the age of discovery

Afflicting human societies for millennia, vitamin C deficiency was well known but little understood during the Renaissance. Outbreaks of scurvy became more regular on European ships as their ranges were extended, especially on voyages to the New World and into the Pacific Ocean (Carpenter, 1986). Accounts of the disorder begin to appear in French naval reports and sailors' journals in the middle of the sixteenth century; among the best known is the description by Jacques Cartier (1491–1557) as scurvy ravaged his crew in 1536 while he explored the St. Lawrence River (Cartier, 1924 [1545]). By the time that Champlain had landed at Saint Croix Island in 1604, he and many of his fellow sailors had themselves witnessed the devastating effects of scurvy on board ship as well as among communities on land. Incorrectly considered two different types of the disorder, various dietary and sometimes dangerous non-nutritional remedies were attempted to treat "land" and "sea" scurvy until Dr. James Lind published the results of his famous experiments administering citrus fruit juice to British sailors in 1753 (Crellin, 2000; McDowell, 2013).

Absent an understanding of the roles that vitamins play in human physiology, the settlers at Saint Croix Island were limited to treating only the scorbutic symptoms that they observed. Champlain and other writers of the period focused on the most grossly obvious symptoms of the mouth and skin. Medical practitioners of the time were virtually powerless to effectively treat the effects of scurvy. As such, autopsies to determine the disorder's cause were reported by several French explorers, including Cartier and Champlain. Autopsies were generally uncommon during this period and performed when all other treatments had proven ineffective.

3.3. Skeletal sample

The remains in 20 of the 25 graves excavated at Saint Croix Island were sufficiently preserved to determine their demographic profiles, but infracranial preservation was poor. The skeletal remains that had been brought in 1969 to Temple University included the mandibles and associated teeth from 19 individuals and the incomplete dentition with mandibular fragments from four others (Table 1). Four crania also comprised part of this original sample, as did the complete palate from one individual and the long bones from five others. Of the five individuals whose long bones were recovered, two also included their crania.

3.4. Analytical methods

Skeletal and dental inventories, demographic assessments, osteometric data, and descriptions of lesions among the skeletal

Table 1

Summary inventory of skeletal remains excavated at Saint Croix Island.

Burial	Bones recovered
1	Calvarium; mandibular fragments; C-1 through C-4; both femora; tibiae, fibulae, calcanei, tali, naviculars, cuboids, and first metatarsals; fragments of eight metatarsals; three cuneiforms
2 ¹	Cranium (fragmented); mandible; both humeri, radii; ulnae, femora, and tibiae; metatarsal fragments
3	Mandible
4	Mandible; L and R maxilla with intact palate
5	Mandibular fragments; both femora, tibiae, and fibulae
6	Mandible
7	Cranium; C-1; C-2; mandible; right femur
8	Mandible
9	Mandible; C-2; C-3; one unsided cuboid; four unsided foot phalanges
10	Mandible; right femur with unfused distal epiphysis
11	Mandible
12	Mandible
13/14	Both mandibular posterior rami with first and second molars present in sockets
15/16	Tooth crowns only (commingled)
17	Cranium; mandible
18	Mandible
19	Mandible
20	Mandible
21	Mandible
22	Mandible
23	Mandible
24	Tooth crowns only
25	Palate, mandible, and teeth

remains from Saint Croix Island were recorded following standard anthropological procedures (Buikstra and Ubelaker, 1994; Moore-Jansen et al., 1994; Ortner, 1994; Paleopathology Association, 1991; White and Folkens, 2005). Because many of the individuals included intact maxillae but no infracranial elements, methods for assessing palatal suture closure (Ginter, 2005; Mann et al., 1987, 1991) were particularly important in estimating the colonists' ages at death. Taphonomic effects on the bone were carefully scrutinized, allowing for rejection of environmental factors as an explanation for damaged bone – which was especially important in the evaluation for the evidence of oral surgery mentioned later.

Champlain's graphic first-hand account of the soft tissue abnormalities he observed among the afflicted colonists was compared to known clinical signs and symptoms of adult scurvy. Lau et al. (2009) provide a modern, detailed account of the signs and symptoms that would be observable without modern testing including initial cutaneous manifestations (perifollicular hemorrhage, petechiae, and ecchymosis) followed by gum disease (gingivitis, periodontitis, with red or purple and swollen gums that may become necrotic), in addition to poor wound healing, fragile hair shafts, and fragility of blood vessels. What follow are hemorrhages seen in the eye, edema in the lower limbs, as well as other musculoskeletal manifestations including myalgia, arthralgia, joint swelling, purpuric rash. The later hemodynamic manifestations would include syncope, hypotension, frank shock, and sudden death.

Differential diagnosis in the skeletal remains was conducted using comparisons with the broad range of previously documented skeletal and dental lesions (Aufderheide and Rodríguez-Martín, 1998; Brickley and Ives, 2008; Mann and Hunt, 2005; Ortner and Aufderheide, 1991; Ortner, 2003; Steinbock, 1976; Zimmerman and Kelley, 1982). Based on these sources and the more specific criteria presented by Brickley and Ives (2008) and Geber and Murphy (2012), the presence of the following cranial lesions were evaluated:

- hypertrophic bone formation of the orbits.

Table 2

Demographic profile of the individuals buried at Saint Croix Island in 1604–1605.

Burial	Sex	Age range at death
1	Male	25–30
2	Male	20–25
3	Male	35–40
4	Male	25–30
5	Male	25–30
6	Male	30–35
7	Male	30–35
8	Male	25–30
9	Male	20–25
10	Male	18–20
11	Male	25–30
12	Male	20–25
13/14 ^a	Indeterminate	20+
15/16 ^a	Indeterminate	20+
17	Male	25–30
18	Male	20–25
19	Male	20–25
20	Male	20–25
21	Male	18–22
22	Male	25–30
23	Male	25–30
24 ^b	Indeterminate	20+
25 ^b	Male	25–30

^a Teeth commingled when recovered in 1969; no other remains identified in 2003.^b Discovered in situ during excavations at Saint Croix Island in 2003.

- abnormal porosity of the anterior surfaces of the maxillae at the infraorbital foramina.
- abnormal porosity across the surface of the palate and the mandibular horizontal rami.
- the presence of a palatine torus.
- porosity at the greater wings of the sphenoid bone, posterior maxillae, and/or lingual surfaces of the mandibular ascending rami where the muscles of mastication (medial and lateral pterygoids and temporalis) originate and insert.
- antemortem tooth loss, especially the incisors, canines, and mandibular premolars.

The infracranial criteria included the presence on the lower limbs of periosteal reactive bone representing subperiosteal hematomas and discoloration of the articular surfaces reflecting inter-articular hemorrhages.

4. Results

4.1. Demographic profiles

Of the 25 individuals excavated at Saint Croix Island, analysis indicated that 20 were men of European or indeterminate ancestry (Table 2). The sex and ancestry of the other five were indeterminate. Fifteen of the 25 individuals (60%) were 20–30 years old at death; three other individuals (12%) were at least 30 years old. Burials 10 and 21 were the youngest individuals (each 18–22 years old) and Burial 3 at 35–40 years old was the oldest individual of the group. The five individuals represented only by teeth or tooth crowns (Burials 13–16 and 24) were all at least 20 years old based on the degree of occlusal attrition.

4.2. Patterns and prevalence of pathological lesions

None of the remains exhibited evidence of antemortem trauma. Evidence of pathology related to infection or inflammation, however, was observed on almost every set of available skeletal remains.

Table 3Prevalence of reactive bone lesions^a in the oral cavities among the individuals buried at Saint Croix Island.

Burial	Hard palate	Palatine torus	Maxillary sinuses	Lingual surfaces of horizontal rami (L/R)
1	N/O	N/O	N/O	N/O/Absent
2	Present	Present	Present	Absent/Absent
3	Present	Present	N/O	Present/Present
4	Present	Present	Present	Present/Absent
5	N/O	N/O	N/O	N/O/N/O
6	Present	Absent	N/O	Present/Present
7	Absent	Absent	N/O	Absent/Present
8	Present	Present	Present	Absent/Present
9	Present	Present	Absent	Absent/Present
10	Present	Present	Present	Present/Present
11	Present	Absent	N/O	N/O/Present
12	N/O	N/O	N/O	N/O/N/O
13/14	N/O	N/O	N/O	Absent/Present
15/16	N/O	N/O	N/O	N/O/N/O
17	Present	Present	Present	Present/Present
18	Present	Absent	Present	Present/Present
19	Present	Absent	N/O	Present/Present
20	N/O	N/O	N/O	Present/Present
21	Present	Absent	Present	Absent/N/O
22	Present	Absent	Present	Absent/Present
23	Present	Present	N/O	Present/Present
24	N/O	N/O	N/O	N/O/N/O
25	Present	Absent	N/O	N/O/N/O

^a Presented as excessive porosity and remodeling.

4.2.1. Lesions of the oral cavity

Among the 25 graves excavated at Saint Croix Island, 16 (64%) included individuals with hard palates sufficiently preserved for visual examination. Of these 16 individuals, 15 (94%) exhibited abnormal porosity of the palatal surfaces, primarily extending from the incisive foramen posteriorly to the first molars and, in some cases, to the transverse palatine suture (Table 3). The porosity was bilateral, mildly to moderately dense, and active. The individual pores measured between 0.5 and 1.0 mm and were more prominent on slightly raised areas (Fig. 1). In addition to the abnormal palatal porosity, mild to moderate palatine tori were present in eight of the 16 observable palates (Table 3; Fig. 1). Also, fragmentation of the maxillae from nine of the men allowed observation of the internal surfaces of their maxillary sinuses. In eight of the nine individuals (89%), the floor of at least one sinus exhibited fine to dense porosity bone that was active at the time of death (Table 3). In three of these cases (Burials 2, 10, and 18), the roots of at least one maxillary molar had perforated the sinus floor prior to death.

Fig. 1. Palatal surface of Burial 4's maxillae displaying abnormal porosity and a palatine torus.

Table 4

Prevalence of reactive bone lesions^a at the attachment sites for the muscles of mastication among the individuals buried at Saint Croix Island.

Burial	Mandible	Sphenoid	
	Ascending rami (L/R) ^b	Lateral pterygoid plates ^c	Pterygoid fossa ^d
1	Present/Absent	N/O	N/O
2	Absent/Absent	Present	Absent
3	N/O/Absent	N/O	N/O
4 ^e	Absent/Absent	Absent	Absent
5	N/O/N/O	N/O	N/O
6	Absent/Absent	N/O	N/O
7	Absent/Absent	Absent	Absent
8	Absent/Absent	Absent	Present
9	Absent/N/O	N/O	N/O
10	Present/Present	Absent	Absent
11	N/O/Absent	N/O	N/O
12	N/O/Absent	N/O	N/O
13/14	Absent/Present	N/O	N/O
15/16	N/O/N/O	N/O	N/O
17	Absent/Absent	Present	Absent
18	Absent/Absent	N/O	N/O
19	N/O/Present	N/O	N/O
20	Absent/Absent	N/O	N/O
21	Absent/Absent	N/O	N/O
22	Absent/Present	Absent	Present
23	Absent/Absent	N/O	N/O
24	N/O/N/O	N/O	N/O
25	N/O/N/O	N/O	N/O

^a Presented as excessive porosity.

^b Distal attachment for the medial pterygoid muscle.

^c Proximal attachment for the lateral pterygoid muscle.

^d Proximal attachment for the deep head of the medial pterygoid muscle.

^e Presents reactive bone bilaterally on the posterior maxillae at the proximal attachments for the superficial heads of the medial pterygoid muscles.

Apart from the maxillary lesions, porosity also was present along the lingual surfaces of the mandibular horizontal ramus in 15 of the 18 men (83%) with at least one observable side (Table 3). Both horizontal rami were observable and the porosity was expressed bilaterally in eight of these 15 individuals (53%). In all of the cases, the porosity was most prominent surrounding alveolar the sockets of molars.

Although the majority of the men excavated at Saint Croix Island had retained their teeth, excessive porosity and exposed coarse trabeculae reflecting inflammation and resorption of alveolar bone was observed in all their observable tooth sockets. These degenerative changes were particularly prominent in the molar sockets where most of the biomechanical forces of chewing are exerted and the lamellar bone is thin.

4.2.2. Lesions associated with the muscles of mastication

Among the 19 men from Saint Croix Island with at least one observable ascending ramus, five (26%) exhibited porosity located on the medial surface near the mandibular foramen (Table 4). In two of these individuals (Burials 10 and 19) the porosity was dense and active. The porosity was bilateral on Burial 10's mandible, but the left ramus from Burial 19 was not observable. Burial 10 was the only individual among the four with porosity whose ascending rami were both observable; his remains demonstrated bilateral lesion formation.

Four of the men exhibited porous lesions on the pterygoid plates and associated fossae of their sphenoid bones. These parts of the sphenoid bone were observable in seven of the 25 men excavated at the island. The four with sphenoid bone porosity represent 57% of these seven individuals (Table 4). Two of the four individuals (Burials 2 and 17) exhibited active porosity on the lateral surfaces of the lateral pterygoid plate where the lateral pterygoid muscles originate. Two other individuals (Burials 8 and 22) exhibited reactive

Fig. 2. Posterolateral aspect of Burial 4's right maxilla exhibiting porosity located superior to the third molar.

bone within the pterygoid fossa, which are located between the medial and lateral pterygoid plates. No lesions were identified on the greater wings of the sphenoid bones. One individual (Burial 4) exhibited active porosity bilaterally on the posterior surfaces of the maxillae, just anterior to the lateral pterygoid plates, where the superficial heads of the medial pterygoid muscles originate (Fig. 2).

4.2.3. Status of antemortem tooth loss

Of the men with observable teeth, most had few dental caries and only mild to moderate occlusal attrition. Of the 14 men with both their maxillae and mandibles available for examination, nine of them (64%) retained all of the teeth in their sockets at death. In three more (21%), the teeth were all present in one arcade. Consequently, 12 of the 14 individuals (86%) died with virtually all of the anterior teeth present in their sockets (Table 5).

4.2.4. Lesions of the lower extremities

Of the 15 individuals with at least one femur or tibia sufficiently preserved for examination, eight (53%) exhibited porotic periosteal reactive bone on diaphyseal surfaces. Six of these cases manifested bilateral lesions (Table 6). The porosity was generally coarse and diffuse with indistinct margins. It was most prominent at the muscle attachment sites on the posterior surfaces of the femora and tibiae but also observed on the anterior aspects of these bones. The periosteal lesions were scored as active in all eight of these individuals; one of them (Burial 5) also exhibited moderate osteomyelitis of both tibiae and the right fibula with both active and healed periosteal lesions. The left and right femora were observable in 13 individuals, and porous lesions were manifested bilateral on seven of them. Of the 11 men with both tibiae observable, four exhibited bilateral porous lesions. Four men exhibited these lesions bilaterally on their femora and tibiae.

Four men exhibited reactive lesions most likely resulting from inter-articular hemorrhages, or hemarthrosis. In Burial 1, areas of porous bone with macroporosity were present within discolored areas of the articular surfaces of the femora, tibiae, and tali (Fig. 3). In Burial 5 numerous small, circular areas of cortical porous bone were present across the posterior halves of both femur heads. Additional areas of porous bone were recorded on the inferior surfaces of his femoral condyles and within the intercondylar notches. Burial 10's right tibia exhibited mild reactive bone with porosity on its proximal articular surfaces and eminences. The coarse porosity was

Fig. 3. Distal articular surfaces of Burial 1's tibiae displaying porosity and discoloration likely associated with inter-articular hemorrhages.

especially prominent along the anteromedial aspect of the lateral eminence where the anterior cruciate ligament attaches. Due to erosion, the proximal left tibia could not be observed. Burial 11 exhibited porosity and remodeling at the articular surfaces of both fibular notches where the distal tibiofibular joints articulate.

4.3. Evidence of medical treatment and autopsy

There is evidence suggesting at least three men had been subjected to medical treatment involving removal of swollen maxillary gingival tissue by the settlement's surgeons and at least one autopsy. The right sides of the palates from Burials 9 and 10 were both absent, yet the left sides lacked any indication of postmortem erosion and appeared healed, with no observable cut marks (Figs. 4 and 5). None of the maxillary right anterior teeth from these men were present. The maxillary left teeth and most of their

mandibular teeth, however, were present and intact in both of these individuals. The maxillary arcade of Burial 22 was completely edentulous with only a thinned and resorbed margin remaining where the sockets for the anterior teeth had been (Fig. 6); there were no observable cut marks. The appearance of this man's palate was inconsistent with postmortem erosion and none of his maxillary teeth were found loose in his grave, although all of his mandibular teeth were present in their sockets. Further, Burial 22's right mandibular teeth displayed occlusal attrition and dentin exposure, indicating that the maxillary teeth had been in occlusion for some time. Burial 10 exhibited clear evidence of a symmetrical, transverse cranial autopsy cut through the cranial vault, allowing the calvarium to be removed for examination of the brain and then replaced prior to burial.

4.4. Observed signs of illness

Champlain's thorough account of the colonists' symptoms and complaints (Champlain, 1922 [1613]: 303–304) is very similar to those itemized in Lau et al. (2009). Champlain paid particular attention to changes in the mouth and dentition, commenting on the swelling of gum tissue ("in the mouths...large pieces of superfluous fungus flesh"), periodontal disease ("which caused a great putrefaction"), limiting their ability to eat solid food ("they could

Table 5
Status of anterior tooth loss among the individuals buried at Saint Croix Island.

Burial	Status of maxillary teeth	Status of mandibular teeth
1	N/O	N/O
2	Present	Present
3	N/O	Present ^a
4	Present ^a	Present ^a
5	N/O	N/O
6	Present	Present
7	Present	Present ^a
8	Present ^a	Present ^a
9	Absent ^b	Present
10	Present (L side only) ^{a,b}	Present ^a
11	N/O	N/O
12	N/O	N/O
13/14	N/O	N/O
15/16	N/O	N/O
17	Present ^a	Present ^a
18	Present	Present ^a
19	Present ^a	Present ^a
20	N/O	Present
21	Present ^a	Present ^a
22	Absent ^b	Present ^a
23	Present	Present ^a
24	N/O	N/O
25	Present ^a	Present ^a

^a All anterior teeth (incisors, canines, and premolars) were present in their sockets when examined in 1994 and/or 2003.
^b Appearance of hard palate indicates probable maxillary surgery.

Fig. 4. Palate from Burial 9 showing probable evidence of perimortem oral surgery.

Table 6
Prevalence and distribution of possible scorbutic lesions among the individuals buried at Saint Croix Island.

Burial	Maxillary surgery	Hard palate	Palatine torus	Maxillary sinuses	Horizontal rami	Pterygoid plates	Pterygoid fossa	Periosteal lesions ^a	Articular porosity ^a
1	N/O	N/O	N/O	N/O	Absent	N/O	N/O	Present	Present
2	Absent	Present	Present	Present	Absent	Present	Absent	Present	N/O
3	N/O	Present	Present	Present	Present	N/O	N/O	Absent	N/O
4	Absent	Present	Present	Present	Present	Absent	Absent	N/O	Present
5	N/O	N/O	N/O	N/O	N/O	N/O	N/O	Present	N/O
6	Absent	Absent	Absent	N/O	Present	N/O	N/O	Absent	N/O
7	Absent	Present	Present	Present	Present	Absent	Absent	Absent	N/O
8	Present	Present	Present	Present	Present	Present	Present	Present	N/O
9	Present	Present	Present	Absent	Present	N/O	N/O	Present	Present
10 ^b	Present	Present	Present	Present	Present	Absent	Absent	Present	Present
11	N/O	Present	Absent	N/O	Absent	N/O	N/O	Present	N/O
12	N/O	N/O	N/O	N/O	Present	Absent	N/O	N/O	N/O
13/14	N/O	N/O	N/O	N/O	Present	N/O	N/O	N/O	N/O
15/16	N/O	N/O	N/O	N/O	N/O	N/O	N/O	N/O	N/O
17	Absent	Present	Present	Present	Present	Present	Absent	N/O	N/O
18	Absent	Present	Absent	Present	Present	N/O	N/O	Absent	N/O
19	Absent	Present	Absent	Present	Present	N/O	N/O	Absent	N/O
20	N/O	N/O	N/O	N/O	Present	N/O	N/O	N/O	N/O
21	Absent	Absent	Absent	Present	Absent	N/O	N/O	Present	N/O
22	Present	Present	Absent	Present	Present	Absent	Present	Absent	N/O
23	Absent	Present	Present	N/O	Present	N/O	N/O	Absent	N/O
24	N/O	N/O	N/O	N/O	N/O	N/O	N/O	N/O	N/O
25	Absent	Present	Absent	N/O	N/O	N/O	N/O	N/O	N/O

^a Lesions observed on lower limb bones.

^b Individual presents evidence of autopsy.

Fig. 5. Palate from Burial 10 showing probable evidence of perimortem oral surgery.

scarcely take anything except in liquid form”), and looseness and loss of teeth (“their teeth barely held in their places, and could be drawn out with the fingers without causing pain”). He discussed the progression of the disease, reporting that the dental changes occurred first and later the men experienced problems with their arms and legs which became swollen, covered with “spots like flea-bites” including “intolerable” pain and difficulty walking. These signs were accompanied with pain “in the loins, stomach and bowels,” bad cough, and shortness of breath. He commented on the resulting fatigue (“consequently they had almost no strength”); limited mobility (“the majority of the sick could neither get up nor move”); and syncope (“nor could they even be held upright without fainting away”). In describing their surgeons’ autopsy findings,

Fig. 6. Palate from Burial 22 showing probable evidence of perimortem oral surgery.

Champlain also described their external examinations of what may have been hematomas (“purple spots”) on the thighs, which they incised with a razor revealing clotted blood.

4.5. Mortality and mass fatality event

Champlain (1922 [1613]: 303–304) provided an account of the prevalence of the illness and death rate among the colonists during the winter months of 1604–1605: “of seventy-nine of us, thirty-five died, and more than twenty were very near it.” This number is consistent with the archeological discovery of 25 graves, along with evidence of erosion of the remainder of the cemetery located near Saint Croix Island’s shoreline. The high mortality impact of the illness that Champlain had identified as scurvy is also consistent with the documented limitations in food availability, which potentially affected the whole colony and put all of the colonists at risk.

5. Discussion

5.1. Differential diagnosis

Acute adult scurvy is a potentially fatal disease. If vitamin C is entirely absent, the only acute skeletal evidence would be residual effects of hemorrhage, some generalized osteoporosis, and possibly death, which are all difficult to positively diagnose in the skeleton. With chronic deficiency, there is likely to be a more obvious skeletal response in the form of diffuse inflammation due to hemorrhage, especially within the joints and under the periosteum. The resulting effects include periostitis with hematoma organization and periodontitis with potential tooth loss, and systemic osteoporosis. Inflammatory and porotic changes would be more pronounced in areas with persistent muscle stress or synarthrotic mechanical strain such as those associated with mastication. Observations of the Saint Croix Island remains are limited by differential preservation of the crania and mandibles compared to the intracranial bones.

Differentiation of adult scurvy from other pathological conditions is accomplished by observing the generalized distribution of the periostitis on all long bones and the generalized osteoporosis rather than increased density. Scorbutic periostitis is diffuse, and the periosteum may appear somewhat separated from the cortex due to the subperiosteal hemorrhage. In contrast, periostitis due to local infection or traumatic insults would tend to be more focal, more tightly bound to the cortex, and might include other characteristics such as cloaca or callus formation which are absent among the Saint Croix remains. In the differential diagnosis of the scurvy, other similar bone-forming disorders that could produce similar must be considered to see if they were instead responsible for lesion formation. In this sample, such diagnostic candidates are treponemal disease, osteomalacia, hypertrophic (pulmonary) osteoarthropathy, fluorosis, and mehlriostosis.

The florid, bulbous, and geographic appearance of treponemal disease lesions of the cranium and long bones is easily seen as a mismatch with the lesions among the men of St. Croix Island, especially since treponemal disease spares areas of joint or muscle strain and is not associated with periodontitis. Although osteomalacia may produce porosity of the trunk and limbs, it neither includes generalized periostitis, nor does the porosity tend to be distributed to the cranium. The lumpy density of hypertrophic pulmonary osteoarthropathy in long bones is differentially thick at midshaft, unlike adult scurvy-affected long bones, which have more uniformly formed periostitis and more porous bone. In contrast to the diffuse periostitis of adult scurvy, long bones affected by

fluorosis have subperiosteal accretions that tend to be more focal, especially at tendon insertions. The porous and less organized texture of adult scurvy periostitis affects long bones generally, and does so bilaterally, whereas in mehlriostosis (Leri’s Disease) one extremity tends to be affected only, and the texture of new bone formation resembles that of melted wax (Long et al., 2009; Ortner, 2003).

Since scurvy often accompanies other nutritional deficiencies including vitamin D deficiency (osteomalacia) and anemia, identifying the specific disorder in dry bone is especially difficult in adults, even with well-preserved remains. Differential diagnosis of the oral abnormalities includes periodontal disease from poor oral hygiene, non-specific infections, and osteopenia resulting from other metabolic disorders. The porosity observed on the hard palates and mandibular horizontal rami could reflect generalized gingivitis and periodontitis. These conditions, however, are typically accompanied by tooth loss and destructive remodeling of the alveolar processes, neither of which were present. Porosity located on the ascending rami at the attachment sites for the pterygoid muscles has been associated only with scurvy. Gingivitis and periodontitis do not affect these areas of the mandible. Further, porotic lesions of the cranium also may result from anemia but in these cases are typically accompanied by enlarged marrow spaces; these lesions have not been documented in the oral cavity. Porous cranial lesions also may develop as a result of osteomalacia, but without intracranial indicators, it cannot be distinguished from those of scurvy. The presence of a palatine torus is generally considered an epigenetic trait but may be associated with scurvy, the possible result of biomechanical chewing stress. Likewise, diffuse porous lesions of the lower extremities may represent systemic or localized infections of various origins (Aufderheide and Rodríguez-Martin, 1998; Ortner, 2003; Steinbock, 1976).

Based on the association of traits in the weighted criteria listed by Brickley and Ives (2008) and the three-level classification described by Geber and Murphy (2012), the skeletal data were re-analyzed (Tables 5 and 7). Of the 15 individuals with observable skeletal elements, eight (53%) were diagnosed with probable scurvy and six (40%) with possible scurvy. Burial 10 probably suffered from scurvy based on the presence of the autopsy cut, evidence of oral surgery together with a maxillary torus, reactive bone across his hard palate, along the lingual surfaces of his mandible, and on the medial surfaces of his ascending rami. There also were active porous lesions on both of his femora. Diagnoses of probable scurvy were made for seven other individuals (Table 7). Two men (Burials 9 and 22) exhibited reactive bone across their palates, the lingual surfaces of their mandibles, pterygoid plates, medial surfaces of their ascending rami, or a combination of these locations along with evidence of oral surgery. Diagnoses were made for the other six individuals based on combinations of these lesions. Possible scurvy was identified among six other men whose remains were less complete or exhibited fewer lesions. Ten other individuals were not sufficiently preserved to apply the diagnostic criteria.

There is presently no single pathognomic indicator of adult scurvy in the skeleton. Diagnosis of the disorder depends on the coincident presence of porotic lesions reflecting its hemorrhagic effects in the mouth and lower limbs, evidence of hemarthrosis, and generalized osteoporosis. Hard palate porosity is too common among archeological remains to be diagnostic alone, and requires the presence of lesions associated with other areas of oral inflammation and at the attachment sites for the muscles of mastication to indicate scurvy. Because of the incomplete nature of the remains from Saint Croix Island, other nutritional disorders and infections cannot be entirely excluded as possible causes for their porotic lesions. Champlain’s historical documentation and context, however, makes it likely that scurvy was a factor in their deaths.

Table 7
Diagnosis of scurvy among the individuals buried at Saint Croix Island.

Burial	Diagnosis	Presence of relevant criteria
1	Probable	Lesions of mastication muscle attachments, lower limb diaphyses (active), and articular surfaces
2	Probable	Lesions of palate with palatine torus, mastication muscle attachments, and lower limb diaphyses (active)
3	Possible	Lesions of palate and horizontal rami
4	Possible	Lesions of palate with palatine torus, horizontal rami, and maxillary sinuses
5	Indeterminate	
6	Indeterminate	
7	Absent	
8	Probable	Lesions of palate with palatine torus, mastication muscle attachments, horizontal rami, maxillary sinuses, and right femur diaphysis (healed)
9	Probable	Evidence of oral surgery; lesions of hard palate with palatine torus, horizontal rami, and lower limb diaphyses (active)
10	Probable	Evidence of autopsy and oral surgery; lesions of palate with palatine torus, mastication muscle attachments, right tibia diaphysis (active), and articular surfaces
11	Possible	Lesions of palate, horizontal rami, lower limb diaphyses (active), and articular surfaces
12	Indeterminate	
13/14	Indeterminate	
15/16	Indeterminate	
17	Probable	Lesions of palate with palatine torus, mastication muscle attachments, horizontal rami, and maxillary sinuses
18	Possible	Lesions of palate, horizontal rami, and maxillary sinuses
19	Probable	Lesions of palate, mastication muscle attachments, and horizontal rami
20	Indeterminate	
21	Possible	Lesions of palate, maxillary sinuses, and lower limb diaphyses (active)
22	Probable	Evidence of oral surgery; lesions of palate, mastication muscle attachments, horizontal rami, and maxillary sinuses
23	Possible	Lesions of palate with palatine torus and horizontal rami
24	Indeterminate	
25	Indeterminate	

5.2. Biocultural aspects of scurvy at Saint Croix Island

Differential diagnoses of adult scurvy at Saint Croix Island utilize a critical evaluation of the appearance and distribution of lesions observed throughout the entire skeleton in combination with historical data. Incomplete or fragmentary remains limit assessment, potentially contributing to the condition known as the “osteological paradox” whereby the absence of skeletal lesions is too simply accepted as an indication of good health (Wood et al., 1992). In fact, skeletal lesions may reflect an individual’s survival despite the presence a disease or disorder, actually a sign of health. However, in this case, it appears clear that the lesions observed here likely owed to deeply dysfunctional physiology and biological stress in the months leading up to their deaths. Bioarchaeology promotes a biocultural approach incorporating multiple sources of evidence, including documentary, ethnographic, and archeological data, into descriptions of health and disease among past populations to overcome, or at least reduce, the effects of the paradox (Armstrong, 2003; Goodman and Leatherman, 1998; Zuckerman and Armelagos, 2011). It is from this perspective that interpretations of the remains from Saint Croix Island are considered.

The men buried at Saint Croix Island were early European explorers and settlers whose voyage to the New World in 1604 ended in tragedy. Analysis of their remains suggests that scurvy

affected at least several of them. As early seventeenth-century trans-Atlantic sailors, they were at high risk for nutritional deficiencies, especially scurvy. Faunal remains recovered from one of their trash pits and cooking vessels from other features at Saint Croix Island, as well as documentary data regarding the culinary trends of the period (Pendery, 2012; Pendery et al., 2012), reflect restricted diets that would not have provided adequate vitamin C to the men, particularly during the severe winter when they were trapped on the island. The archeological data indicate that they subsisted largely on salted meat and grain from France, local wild-fowl, fish and shellfish, seal meat, and possibly native fruits and berries, but the latter was restricted to the noblemen among the group. Spanish wine and cider also were available, although the cider froze during the winter as did their fresh water supplies. Champlain (1922 [1613]: 277–278) wrote that they had planted wheat on the mainland and built an oven for baking, but that nothing grew well on the island itself. Except for the berries, clams, and mussels, these foods contain little vitamin C and even less if cooked. Finally, Samuel de Champlain’s own journal provides a first-person account of the symptoms of the disease that he identified as the cause of death for 35 of his comrades.

Marc Lescarbot, a Parisian lawyer who spent the winter of 1606–1607 in New France with Champlain and several of the other Saint Croix Island survivors, reported that the first symptoms of scurvy became apparent at Saint Croix Island approximately three months after the first snowfall in October 1604 (Lescarbot, 1911 [1618]). Based on experimental studies, clinical scurvy generally becomes manifest three to four months after severe vitamin C deficiency begins. Consequently, it is very likely that most of the 79 settlers were already subclinically deficient in vitamin C when they landed at Saint Croix Island and that the subsequent absence of fresh fruits and vegetables resulted in the outbreak of severe scurvy beginning in January 1605. Lescarbot (1911 [1618]: 258) noted that the “season of mortality for [scurvy] is the end of January, the months of February and March, during which the patients generally die, each in turn according to the time at which the first symptoms appeared.”

Other clinical data from experimental scurvy recorded among adults (Crandon et al., 1940; Hodges et al., 1969; Leggott et al., 1986, 1991; Väänänen et al., 1993) indicate that, in manifest scurvy, the gingiva swell and become blackish-red in color as a result of localized hemorrhages. This process often begins at the cemento-enamel junctions of the molars, where the reactive bone lesions observed among the mandibles at Saint Croix Island were concentrated. Ulceration of the gums follows, accompanied by the formation of pyogenic fistulae along the alveolar processes. Scorbutic adults also present proliferation of the interdental papillae that leads to formation of pea-sized nodules between the teeth (Halligan et al., 2006). These nodules often form between the anterior teeth and are particularly noticeable; Champlain’s reference to “fungus flesh” may refer to these lesions. Lescarbot included a similar account of the gum lesions based on his conversations with the Saint Croix Island survivors: “Meanwhile the poor patients lay suffering. . . hindered by a foul flesh which grew very abundantly in their mouths, and which, when they thought to root it out, renewed itself daily more abundantly than before” (Lescarbot, 1911 [1618]: 257–258).

Some researchers have identified inflammation from localized hemorrhages at muscle attachment sites as pathognomonic of scurvy, especially the muscles of mastication (the temporals, medial pterygoids, and lateral pterygoids). These three paired muscles extend from the sides of the cranium to different locations on the medial surfaces of the ascending ramus of the mandible. Porosity at their insertion sites in dry bone has been interpreted as reactions to leaking of blood from branches of the internal maxillary artery, which lie deep to and supply these muscles when they are abraded when they contract during chewing (Brown and Ortner,

2011; Uysal et al., 2011). Lesions located on the medial aspects of the ascending rami are commonly cited as evidence of subadult scurvy (Geber and Murphy, 2012; Maat, 2004; Ortner, 1984, 2003; Ortner and Erickson, 1997; Ortner et al., 1999, 2001) but are not as well represented among adults.

Although swollen and bleeding gums are clinically documented scorbutic symptoms, the traditional sign of the disorder in adulthood is the loss of teeth. Numerous anecdotal accounts written over the centuries include this claim (Bown, 2003; Carpenter, 1986) and paleopathologists have interpreted the absence of anterior teeth as indicative of scurvy, especially if porotic lesions or ossified subperiosteal hematomas are present elsewhere in the skeleton (e.g., Saul, 1972). In his journal, Champlain specifically linked the loss of teeth among the settlers at Saint Croix Island to scurvy: “Their teeth barely held in their places, and could be drawn out with the fingers without causing pain” (Champlain, 1922 [1613]: 303). Modern clinical data from experimental scurvy in adults, however, indicate that tooth loss is more likely the result of poor dental hygiene than a direct effect of the disorder (Leggott et al., 1986, 1991; Touyz, 1997). Assuming that some of the individuals recovered from Saint Croix Island were scorbutic when they died, the dental evidence from this group is more consistent with the experimental clinical data indicating that tooth loss is an unreliable indicator of scurvy.

Despite its depiction in popular culture and Champlain's own journal description, more than 85% of the observable individuals had died with all of their anterior teeth intact except for the three men whose swollen maxillary gums appear to have had been cut away by the settlement's surgeons. Lescarbot provides a vivid description of the excessive swelling of the gums and associated oral tissues in the cases of scurvy that he observed at Port-Royal, Nova Scotia in 1606 and 1607, which was the settlement that the survivors from Saint Croix Island built in 1605. In his discussion of scurvy (1911 [1609]: 267), he noted that, “And our patients, even though their mouths were sore, and they could not eat, never lost their taste for wine, but took it through a spout, which saved several from death.” Postmortem erosion could account for the loss of the palatal bone and lack of loose teeth. However, the straight margins and remodeled (healed) appearance of the remaining maxillae are more consistent with Champlain's description of surgery than an alternative taphonomic explanation.

The excavation of Burial 10 in 2003 confirmed Champlain's description of the autopsies that were performed in an attempt to combat the disease that stalked their settlement. Burial 10 was also one of the three men who exhibited evidence of oral surgery, and his remains exhibited porous lesions of the hard palate, the horizontal and ascending rami, and right tibia. The remains of his cranium currently represent the earliest evidence of a European autopsy conducted in the New World (Crist and Sorg, 2004). In their journals, both Champlain and Cartier described numerous autopsies that their surgeons performed in New France specifically to investigate scurvy.

6. Conclusion

Documentary, archeological, and skeletal data support Samuel de Champlain's account of scurvy at Saint Croix Island during the winter of 1604–1605. While limited by the small sample and taphonomic deterioration, the skeletal evidence suggests that at least 14 of 25 settlers probably or possibly had adult scurvy when they died. The skeletal data also confirm Champlain's descriptions of their rudimentary attempts to treat it and diagnose it via autopsy. Far from eradicated, scurvy continues to afflict modern people in all societies who have limited access to fresh foods, whose communities are under siege, or who may have a heightened genetic predisposition for the disorder. Beyond being the scourge of sailors,

scurvy truly is the *mal de la terre* as Champlain called it four hundred years ago, a truly ancient disease that is now better understood but remains unconquered.

Uncited reference

Hirschmann and Raugi (1999).

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