Maritime Occupational Disease: "the Scurvy"

Louis Arthur Norton

Á l'époque de la voile, les marins sont souvent morts d'accidents ou de maladie. Parmi les dangers inhérents à la vie maritime, le scorbut s'est transformé en une des maladies du métier les plus dévastatrices de l'histoire. Du seizième au dix-neuvième siècle les rapports indiquent qu'approximativement deux millions de marins sont morts de causes attribuées au scorbut, une maladie marquée par des manifestations débilitantes physiques et mentales. Son histoire, jusqu'au vingtième siècle, se retrouve dans l'histoire de l'exploration aussi bien que dans celle de la médecine. Cet article trace leurs histoires parallèles et fascinantes, ainsi que la science qui premièrement a fourni le traitement et plus tard l'étiologie du "scorbut."

During the age of sail ships, especially after 1492 when ships sailed out of sight of land for prolonged periods of time, many sailors were lost to disease. One specific malady became inherent to maritime life. "The scurvy" evolved into arguably one of history's most devastating occupational diseases. From the sixteenth through the nineteenth century, collected historical records indicate that approximately two million deaths from scurvy occurred among the world's sailors.[1]

The debilitating nature of the "the scurvy" is illustrated by the following description of one case of the disease:

> I had the experience of this destructive disease [scurvy] for about three months in a passage to the East-Indies, in the year 1738-9 . . . After eating a hearty breakfast of salt beef, I found myself taken with a pain under my left breast, where I had formerly received a dangerous blow. From this time the sea scurvy increased upon me, as it had done upon many others, a good while before me; and I observed that they soon took to their hammocks below, and became black in their armpits and hams, their limbs being stiff and swelled, with red specks, and soon died; . . . the disease . . . increased so that my armpits and hams grew black but did not swell, and I pined away to a weak, helpless condition, with my teeth all loose, and my upper and lower gums swelled and clotted

1 C. P. McCord, "Scurvy as an Occupational Disease," *Journal of Occupational Medicine* 13 (1959), 318.

> together like a jelly, and they bled to that degree, that I was obliged to lie with my mouth hanging over the side of my hammock, to let the blood run out, and to keep it from clotting so as to cloak [choke] me . . . [2]

The medical science history of most disease entities typically goes through four phases. First is the description of the symptoms or presentation of a disease usually of unknown cause. Second may be the serendipitous discovery of empirical remedies for the disease. This is followed by the identification of the specific cause, if it is not obvious. This perceived mechanism must fit the accepted paradigm of disease among medical practitioners of that specific time. The final phase is finding the mechanism of action or cause of the cure so that the disease can be completely understood.[3] The disease scurvy is a classic example of this concatenation. What makes this unique is the relationship of scurvy to the maritime history of the western world.

The History of the Disease

Scurvy most certainly occurred on land, especially in the late days of winter before plant life was rejuvenated. This was a time of temporary nutritional deficiency when lack of vitamin C as well as thiamin, niacin, and riboflavin produced a variety of dietary related maladies. Scurvy also was seen in prison populations where the diet of the incarcerated was often inadequate.[4] The description of scurvy in literature was rare,[5] however the disease became a public major health maritime problem around 1420 through 1460.[6] Dom Henriques, Portugal's Prince Henry the Navigator, had collected a critical mass of scholars (astronomers, mathematicians and geographers) at the seaport town Sagres. Their scientific work and the daring of the Portuguese mariners led to the Age of Exploration. Although seafarers of the time had sailed out of sight of land for several days, the impetus to discover new lands meant that they might be at sea for many weeks and months. Prolonged voyages as well as extended naval blockades of seaports,

2 W. A. Hutchinson, *Treatise on Naval Architecture* (Liverpool, 1794), 286-9.

3 The elucidation of the mechanism of a disease is the essence of medical basic science.

4 E. G. Burrows, *Forgotten patriots: The Untold Story of American Prisoners during the Revolutionary War* (New York, 2008), 20, 60, 105.

5 The description of scurvy as a disease overlapped with the malignant diseases. Remedies were empirically found, but surgeons and scientists had only vague understandings of its cause for centuries. Bleeding a patient was used as a treatment for scurvy. Some physicians prescribed "acidic medicine," a concoction of spices and herbs mixed with toxic substances like mercury, sulphuric acid or arsenic as a cure. Others used aggressive physical treatments such as the burial of a patient to his neck in sand. For some time medicine was synonymous with natural magic.

6 In 1419 two Portuguese captains under Prince Henry's direction landed on Madeira. In 1427 another reached the Azores. By 1434 a Portuguese ship commanded by Gil Eanes rounded Cape Bojador, and eight years later Nuno Tristaõ passed Cape Blanco. These expeditions led to a spurt of maritime activity. More than thirty ships licensed by the prince sailed to Guinea between 1444 and 1446. Several Portuguese navigators reached Senegal in 1445. Diniz Diaz rounded Cape Verde in 1446, and in that same year Alvaro Fernandez pushed on just short of Sierra Leone; Pedro da Sintra would reach it in 1460, just months before Henry's death.

frequently led to the vitamin deficiency disease scurvy.[7]

The food on sailing vessels was usually adequate in quantity (calories), but not necessarily high in quality. The provisions generally consisted of some livestock to be butchered or used onboard (chickens, cows and pigs), sugar, salt, flour, legumes, small amounts of perishable vegetables such as potatoes and turnips, lard, hard cheese, dried meats and fruits, hardtack, potable water, casks of beer, and occasionally wine. Shortly after Joseph Priestly discovered oxygen in 1774, a hypothesis about spoilage called "fixed air" entered the maritime community.[8] This theory claimed that stored food on shipboard lacked oxygen or caused it to lose oxygen and was much less healthy than fresh food. After a few weeks at sea, water frequently became non-potable, a scum of algae and bacteria proliferating to form a noxious soup. An open butt left sitting in the open air produced an uninviting odor. Thus beer, which was relatively nonperishable, was an important source of drink.[9]

Perishable foods were quickly consumed and the diet at sea became monotonous and unbalanced, the most happily anticipated part of the sailing ship's routine was the issue of grog, a mixture of a gill (4 ounces) of high-proof rum diluted by three gills of water.[10] The symptoms of scurvy appeared slowly, but steadily increased through approximately two and a half months at sea.[11] Normally it takes about four months for the clinical symptoms of scurvy to appear, but at sea outbreaks of dysentery, extremes of weather and long hours of stressful work aloft took an unusual physical toll on the crew. Ships' logs and memoirs of voyaging abound with grisly descriptions of scurvy and its not infrequent incapacitation of such a large proportion of a crew that a ship's mission had to be foreshortened or abandoned.

According to the *Oxford English Dictionary* the first written use of the word scurvy was in 1565: " our legs . . . swolne and every joint withal. With this disease, which, by your leave, the Scuruie men do call." There were many variations of spelling such as scurvie, scurvey, skirvye, scurby, skyrby, scorbie and scorby and the Latin-like scorbutus (the origin of scorbutic acid, the active ingredient for its cure).[12]

7 L. A. Norton, "The Legacy of Prince Henry: The Navigator" Re-examined," *The Mercator's World* 6 (2001), 44-9.

8 Z. B. Friedenberg, *Medicine Under Sail* (Annapolis, 2002), 56.

9 H. Melville, *Moby-Dick* (Evanston, 1988), 446. "A long detailed list of the outfits for the larders and cellars of 180 sail of Dutch whalemen; . . . [including] 10,800 barrels of beer."

10 The rum ration was first introduced into the British Navy in 1731 and abolished 1 August 1970. The US Navy substituted whiskey for rum in 1806. The enlisted man alcohol ration ended in 1862; the officers' shipboard wine mess was terminated in 1914.

11 The clinical signs of scurvy include raised red spots around the hair follicles of the extremities, buttocks and back, hemorrhaged capillaries around the hair follicles (scurvy spots) sometimes coalescing into red and blue patches (scorbutic rosary) over the ribs and sternum, weak, stiff, swollen, and painful joints that are easily luxated, dolorous periosteal hemorrage, bulbous and hemorrhagic gingiva, loose and brittle teeth, ulcerative oral mucosa and fetid breath. Wound healing is slowed and scaring abnormal. Lethargy secondary to anemia from multiple episodes of bleeding is common.

12 Quote from R. Hakluyt, *Diver's Voyage*s *Touching the Discovery of America and the Islands*

In 1596 the renowned English surgeon William Clowes described the symptoms of scurvy as an expression of the then popular theory of disease known as "bodily economy." Later, the Dutch physician Hermann Boerhaave theorized that scurvy was caused by blood serum being too thin and acrid caused by damp and cold climate and foul vapors.[13] Unfortunately the term "scurvy" became generic for a number of maladies especially nutritional deficiencies such as beri-beri that produces some similar symptoms. This imprecision in diagnosis made tracing scurvy's appearance and treatment in the medical literature of the time very confusing.

Discoveries of Many Remedies

The Portuguese explorer Vasco da Gama skirted the African coast during 1498-99. By the time da Gama rounded the Cape of Good Hope, about one hundred of his one hundred and seventy men had died of scurvy.[14] The explorer observed, "many of our men fell ill here, their feet and hands swelling, and their gums growing over their teeth so that they could not eat."[15] In the words of a modern historian of that voyage: "[i]f the dead who had been thrown overboard between the coast of Guinea and the Cape of Good Hope could have had headstones placed for them on the spot where he sank, the whole way would appear one continuous cemetery."[16] When the ships reached the East Coast of Africa, they bartered for some oranges with Moorish traders. Shortly thereafter all of da Gama's remaining sick recovered their health.[17]

Antonio Pigafetta, an Italian gentleman/adventurer, accompanied Ferdinand Magellan on his round-the-world voyage. Pigafetta noted:

> Wednesday, November 29, 1520, …We were three months and twenty days without getting [any] kind of fresh food. We ate biscuit, which was no longer biscuit, but powder biscuits swarming with worms, for they had eaten the good. It stank strongly the urine of rats. We drank yellow water that had been putrid for many days. We also ate some ox hides that covered the top of the main-yard to prevent the yard from chafing the shrouds, and which had become exceedingly hard because the sun, rain, and wind. We left them in the sea for four or five days, and then [put] them for a few moments on top of the embers, and so ate them; and often sawdust from boards. Rats were sold for one-half ducado apiece, and even then we could not get them. The gums of both the lower [and] the upper teeth of some of our men swelled, so that they could not eat under [any] circumstances and therefore died. Nineteen men died from that sickness. . . [18]

Adjacent, London, 1582; *Oxford English Dictionary* (Oxford University Press, 1981).

13 H. Boerhaave, *De Materia Medica, et Remediorum Formulis Liber* (Leyden, 1727).

14 D. J. Boorstin, *The Discoverers: A History of Man's Search to Know his World and Himself* (New York, 1983), 177 and 288.

15 K. J. Carpenter, *The History of Scurvy and Vitamin C* (Cambridge, 1986), 1.

16 R. Allison, *Sea Diseases* (London, 1943), 15.

17 E. G. A. Ravenstein, *Journal of the First Voyage of Vasco da Gama, 1477-1499* (London, 1898), 20-1 and 124.

18 E. S. McClusky, "Which Vertebrates Make Vitamin C?," *Origins* 12 (1985), 96-100.

Rats as well as guinea pigs and some bats synthesize their own vitamin C, therefore consuming rats caught onboard was potentially a scurvy preventative measure.

When Francis Drake's expedition encountered a williwaw's violent wind off Cape Horn in 1578, he sought shelter on shore. Noting that some of his crew had contracted scurvy, the explorer had sap collected from a beech tree found on shore. Drake added this to their wine and cured all but two of his men who died of complications of the disease. As a result of the success of this empirical remedy, Drake had a large beech cut down and a section of the trunk placed in the hold of the *Golden Hind*.[19]

In 1535 the crew of an expedition led by Jacques Cartier became ice bound in the St Lawrence River near what is now Quebec City. They were obviously suffering from the symptoms of scurvy, teeth falling out, gums putrefying, swollen limbs, and debilitating pain. Cartier heard that a beer made from boiled ground bark of evergreen trees drunk every other day or the residue applied as a poultice to swollen and infected legs might cure scurvy. Cartier's sailors found the medicine very unpalatable, but those who drank it quickly felt better and, after two or three days, appeared to be completely cured. Subsequently the sailors pulled this miraculous tree (*Thuja occidentalis*) to pieces. Sailors frantic for relief from "the scurvy" consumed almost every leaf and piece of bark of the tree.[20]

In 1585 Peder Claussøn Friis, a Danish priest and author, noted that the Norwegian natives were healthy, but visiting foreigners, presumably sailors, frequently were afflicted by "scorbutus." Scurvy struck those who disliked or could not digest local food such as halibut and other fat fish normally consumed without salt. Fatty fish consumed without salt can be difficult to digest, but high fat fish are anti-scorbutic. Animal meat from seal, whale, musk ox, caribou and polar bear contain surprisingly high levels of vitamin C. Plants of the far north like mountain sorrel, licorice root and Yredysarum alpinurun also are relatively rich in vitamin C. That is why Inuits and other dwellers of the barren northern climates do not get scurvy. Friis mistakenly reasoned that scurvy was due to indigestion; he was only partly correct in identifying as a cure the stalk and root of the herb Angelica (*Angelica Archangelica)* that grew in the region in some abundance.[21]

From the sixteenth through the eighteenth century Europeans cultivated *Cruciferea* or *Brassicaceae* (types of mustards) as anti-scorbutics. These were from the species *Cochlearia officinalis* – commonly called "scurvy grass" or "spoonwort." When making landfall, voyagers looked for these plants or others like them. Voyaging to North America led to the discovery of Native American anti-scorbutics, the ingestion of spruce essence. Indigenous Americans chewed spruce gum and brewed a kind of tea that

19 S. E. Morison, *The European Discovery of America: The Southern Voyages* (New York, 1974), 646.

20 S. E. Morison, *The European Discovery of America: The Northern Voyages* (New York, 1971), 419.

21 ["Description of Norway and Adjacent Islands"], quoted passage translated by K. Jensen. The green leaves and stems of Angelica contain up to 96 milligrams vitamin C per 100 grams, but the root is almost devoid of the vitamin.

contained the sap of the spruce twigs. Similarly a type of spruce beer was brewed in parts of Scandinavia where the evergreen is abundant. The exact ethnic origin of spruce beer is obscure, but likely was found independently in many cultures.[22] Spruce essence was used as a comprehensive medicine; a local anesthetic, counterirritant, stimulant, and wound palliative to treat abrasions, arthritis, boils, burns, catarrh, consumption, cough, diarrhea, dyspepsia, dyspnea, headache, inflammation, nephrosis, ophthalmia, phthisis (tuberculosis), renosis, rheumatism, sores, sore throat, stomach, stones, tumors, and general soft tissue wounds as well as scurvy.[23]

John Woodall, the first surgeon general to the East India Company and surgeon at St. Bartholomew's Hospital in London, was prescient concerning the most advantageous cure of scurvy. In the preface of his 1639 volume he discussed the diagnosis and treatment scurvy he called *Latine Scorbutum*.

> [W]e have in our owne country here many excellent remedies generally knowne, as namely, Scurvy-grasse, Horse-Reddish roots, *Nasturtia Aquatica* [sic], Wormwood, Sorrell, and many other good meanes... to the cure of those which live at home...they also helpe some Sea-men returned from farre who by the only natural disposition of the fresh aire and amendment of diet, nature herselfe in effect doth the Cure without other helps... [At sea,] the Lemmons, Limes, Tamarinds, Oranges, and other choice of good helps in the Indies... do farre exceed any that can be carried tither from England.[24]

Woodall concluded that the beneficial ingredient was the acidity found in citrus and from this “salts of lemon” became an assumed remedy. Unfortunately this was citric acid, a substance that made for a pleasant drink, but lacked the anti-scorbutic properties of ascorbic acid.[25]

By the end of the sixteenth century, the Dutch colonized the African coast and planted citrus groves for their seamen. The East India Company’s vessels started to carry citrus juice, thus securing their hold on South Africa and the Cape of Good Hope settlement. James Lancaster, a British maritime captain prevented scurvy in a voyage from India in 1601 by having his crew consume lemons and oranges obtained in Madagascar.

Nathaniel Butler, the English maritime author and one time governor of Bermuda, described a similar treatment in his *Boeteler’s Sea Dialogues*, published in 1634:

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22 The ingredient that gave the beer its medicinal power was *Resina Pini*, a resin of the Norway Spruce. This cure worked but by luck since boiling this concoction too long likely would have destroyed much of the activity of the vitamin C. The spruce extract has been shown to contain on the order of 200 milligrams ascorbic acid per 100 grams of needles or shoots.

23 C. Erichsen-Brown, *Use of Plants for the past 500 years* (Aurora, 1979).

24 J. Woodall, *The Surgeon's Mate, or Military and Domestique Surgery* (London, 1639), 160.

25 J. Druett, *Rough Medicine: Surgeons at Sea in the Age of Sail* (New York, 2001), 143.

> Admiral: . . . the difficulty consisteth in that our common seamen are so besotted in their beef and pork that they had rather adventure on all the calentures and scurvies in the world than to be weaned from their customary diet.
> Captain: . . . their cassada, [cassava prepared from the tuberous roots of the mandioc), pompians [pumpkins], potatoes, plantains, oranges, lemons, limes, pines; which are excellent against the scorbute; so that the Dutch men-of-war, which yearly haunt all those coasts, do continually maintain themselves. . .[26]

Scurvy also harried French mariners, although they had a vague supposition about its management as revealed in the following passage:

> [Scurvy] usually appears during long journeys at sea because of unsanitary conditions such as not bathing in clean water and not changing into clean clothes and because of [bad] air from the sea and a lack of use unspoiled water. Cold water and sleeping outside during the day also cause this disease. To avoid this disease, one should abstain from drink [alcoholic beverages], sleep during the day and not exercise. There is no cure for the disease, but some people have found relief from soft water, oranges and fruits. Lack of salt necessary to preserve food is the cause of this disease.
> [Scurvy] is very debilitating or fatal if nothing is done about it. A change of air and environment can be helpful. Mustard extract has been shown to be an excellent treatment . . . All bitter plants are recommended as remedies whether they are dried or cooked and the greens of these plants are [especially] very good . . . Cochlcaria of Septentrionaux, a weed of the sea, is also suggested . . . Other weeds such as those related to watercress, as well as a red soil found in Norway, and the extracts of oranges and lemons are also very useful.[27]

Theories about the etiology and cure of scurvy abounded in maritime nations. An interesting piece from 1752 in an archaic "Old Dutch" roughly translates as follows:

> Various practitioners have postulated that the salty sea-vapor causes illnesses. Our country [Holland], lying next to the North Sea, therefore is visited by the scorbutus [scurvy], and this illness affects all countryside's and peoples, all crewmembers, wherever they navigate; . . . however [it is] easy to cure with just fresh little lemons: newly arrived [scurvy victims], [were found in the hold of] a slave-carrier. This scorbutus is not from the sea-vapor, idleness or the stink in the Ship's hold where they [the slaves] were locked up like criminals, but the air within the ship, moldy cheese, and meat and bacon that is too salty creates the mold-illness
> It appears that insufficient or polluted water is the cause of scorbutus. Water, if good, and clear, is refreshing by character. It can be easily consumed with food and quench the thirst. It can be used to mix and/or dissolve some foods. Also it may serve as a laxative. These beneficial elements makes it a necessity, but if it is tainted, it is also cause of illness.[28]

By the middle of the 1700s, Britain's scientific community largely agreed that

26 N. Boteler [Nathaniel Butler, pseud.], *Colloquia Maritima* [Sea Dialogues] (London, 1634), 65-6.

27 G. Fournier, Hydrographie: *Du Scurbut & Autres Maladies de la Zone Torride, que doit connoistre tout Chirurgien qui monte sur Mer* (Paris, 1667).

28 T. Abraham, *Geneeskunst der Heelmeesters, tot dienst der Zeevaart* (Amsterdam, 1752).

fresh fruit, particularly citrus, could cure scurvy. Their challenge was to find the etiology of the disease. There were many competing theories, but the one that had the most proponents was called "pneumatic chemistry."[29] The scientists and physicians had accumulated data on the physiology of the lungs and had a rudimentary knowledge of the physics of elasticity. The chemistry and physics of gases was being extensively studied. This knowledge led them to presume that when the balance of the physiological gases get out of balance, oxygen decreases and putrefaction occurs. They postulated that the result was scurvy; an incorrect answer, but the theory led to far better ventilation and sanitation on ships.

In 1753 James Lind, a surgeon's mate in the Royal Navy, published the classic work "A Treatise of the Scurvy" in which he described a controlled clinical nutrition study on twelve sailors with scurvy. All had the symptoms of the disease, having lived in the same place and consumed the same diet of "water gruel sweetened with sugar in the morning; fresh mutton broth often times for dinner; at other times puddings, boiled biscuit with sugar etc.; and for supper barley, raisins, rice and currants, sago and wine, or the like." Two patients were given a quart of [apple?] cider a day. Two others took an "elixir vitriol three times a day upon an empty stomach" and an acidulated gargle for their mouths. Another pair was given "two spoonfuls of vinegar three times a day upon an empty stomach," plus the gargle regime. The two sickest patients were put under a course of a half-pint of seawater per day. Another two were given two oranges and one lemon every day. "These they eat with greediness at different times upon an empty stomach. They continued but six days under this course, having consumed the quantity that could be spared." The two remaining patients were given a honey based nutmeg concoction three times a day, followed by three or four daily purges during this course of treatment.

The results were that "sudden and visible good effects were perceived from the use of the oranges and lemons; one of those who had taken them being at the end of six days fit four duty . . . [I] observe that the result of all my experiments was that oranges and lemons were the most effectual remedies for this distemper at sea. . . "[30] (Lind designed his study to prove that vinegar was not a cure for scurvy. The finding that citrus was curative was surreptitious and not initially publicized.)

The log of the *Discovery* reveals that Captain James Cook and his crew brewed spruce beer while exploring Nootka Sound in 1778. Cook was also an advocate of wort (malt) as a cure for scurvy usually combined with a portion of a rob (a ten fold concentration) of lemon juice and also brewed a spruce beer concoction.

The evidence that citrus was a preventative as well as a curative agent for scurvy became accepted and was introduced into the British grog ration. Some ships resisted the lemon juice because it changed the taste of one of the few rewards of life at sea. (Ironically "lime and lager" would later become a popular pub beverage.) The "cocktail"

29 Carpenter, *The History of Scurvy and Vitamin C*, 75.

30 J. A. Lind, *A Treatise of the Scurvy in Three Parts: containing an inquiry into the nature, causes and cure of that disease, together with a critical and chronological view of what has been published on the subject* (London, 1753).

was also greeted with suspicion by some officers and shellbacks, a "public health procedure" that they did not trust, not unlike the public mistrust of fluoridation of water supplies in the second half of the twentieth century.

The Royal Navy had difficulty obtaining citrus in quantity, because most of the fruit was grown in Spain or parts of the Mediterranean under Spanish or Barbary control. When England was not actually at war with Spain, its diplomatic relations with its southern neighbor were strained. The four Barbary States of North Africa — Morocco, Algiers, Tunis, and Tripoli — were relatively lawless. They demanded tributes of money, harassed seaborne commerce, seized ships, ransomed crews or sold them into slavery. In spite of these obstacles the British did manage to obtain citrus, largely from lime plantations in both the East and West Indian colonies. In order to preserve the juice they boiled it into a concentrate and added sugar. Unfortunately the boiling and storage method decreased much of the vitamin C content of the juice.

In 1867 Lauchlan Rose patented a method for preserving vegetable juices after noting that sulphur salts acted a preservative agent for many perishable juices. By 1879 he had registered nine patents on bottles and bottling methods and, shortly thereafter, Rose's Lime Juice Cordial became a widespread means of obtaining well-preserved lime juice in any ship or household.

Etiology and Biological Mechanism of the Disease

The crucial questions are as follows: What is the cause of scurvy? What is its remedy? Can it be prevented? Scurvy is the result of the impediment of a crucial biochemical step in the production of collagen. Collagen, a complex protein, exists in the body as twisted strands like the stout manila rope of the running rigging of a sailing vessel.[31] Collagen binds groups of cells together to form anatomical connective tissues, the ubiquitous connective tissues of the joint ligaments (the PDL), the infrastructure of most organs, and the webbing to hold the vast vascular system together. Poorly formed collagen can cause the walls of blood capillaries to break down and secondary hemorrhaging can ensue throughout the body (perifollicular papules, patches of petechiae and ultimately ecchymoses becoming extensive areas of purpura). The loss of the capillary "glue" that holds them together produces the most visible symptoms of scurvy,

31 The precursor molecule of collagen, procollagen, is made up of amino acids. In the amino acid sequence in procollagen, every third amino acid is a glycine and there is a high frequency of hydroxyproline and hydroxylysine. Vitamin C or ascorbic acid (AA) participates in the synthesis of procollagen as a reducing agent that keeps prolylhydroxylase in an active state. Prolylhydroxylase is activated by the ferrous iron molecule (Fe2+) that is relatively unstable and easily oxidized. AA maintains Fe in the 2+ form and not in the more stable 3+ form, thus acting as an enabler or a cofactor. AA enables prolylhydroxylase to be active and make hydroxyproline and hydroxylysine from proline and lysine respectively. This chemical reaction, the hydroxylation of procollagen, is a post-translational modification in the rough endoplasmic reticulum where the biochemical cascade events occur creating the triple helixes characteristic of the collagens. Clinically the imperfect collagen needed for connective tissue (blood vessels, bones, joints and tooth support) are more easily broken down, particularly when during an elevated body temperature.

including swollen purple spongy gingiva, loose teeth, bleeding gingiva, and the subsequent decline in oral hygiene.

In the early nineteenth century, humoural medicine was supplanted by clinical medicine, that is the recording of external signs as well as symptoms as a means of diagnosing internal problems. Within this framework scurvy was understood as disease or product of anatomical and physiological dysfunction. Lind had established that citrus fruit cured scurvy and manipulation of a patient's diet had ancient roots in medicine. Modern medicine's foundation comes from ancient Greek culture where a high priority was placed upon healthy life styles. The ancient Greeks' major strides in medical knowledge were the result of studying the cause of disease rather than looking solely at the symptoms when prescribing a cure. Their doctors practiced medicine by using herbs either taken internally or applied, and thus the Greeks accumulated an extensive knowledge of herbs and their properties. They prescribed dietary remedies under the supposition that good health was derived from a balanced diet and that a dietary imbalance could precipitate "bad humours" and illness. Although the Greeks made careful observations, they did not perform what we would consider scientific experiments. A familiar dietary measure for communal health continues today. The biblical Kashrus Laws (*Leviticus 11* and *Deuteronomy 17*) were considered commandments from God, but in reality they served as dietary public health or preventive medicine measures in a land where certain foods were recognized as a source of illness. The theory that germs or microbes were a widespread cause of disease was not widely accepted until the end of the nineteenth century. A progression of medical knowledge over time went from ignorance to discoveries, but not necessarily the "correct" understanding of the complete etiology and underlying disease process. Medical science (sometimes crude and sometimes sophisticated) has frequently been able to find a cure in the absence of understanding. This was true of scurvy where a not well-understood cure had been deduced empirically long before an understanding of the disease was elucidated.

Still, replacing a missing dietary component did not fit the popular medical paradigm of disease at the beginning of the nineteenth century. The prevalent explanation for the etiology of disease was the humoural theory, the adjustment of bodily fluids. This was the rationale behind bleeding the patient and the curative use of leeches. By the end of the nineteenth century there was general acceptance that a disease could be prevented or cured by dietary manipulation. But even then it came into conflict with the then novel "germ theory" of disease where some newly converted zealots argued that infection was an explanation of the etiology of scurvy.

It was not until 1907 that it was reported that scurvy could be induced in guinea pigs and cured by dietary manipulation.[32] The guinea pig model was used to assess the antiscorbutic value of different foodstuffs that identified the thermolabile nature of the

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32 A. Holst and T. Fröhlich, "Experimental studies relating to ship beri-beri and scurvy, (II). On the etiology of scurvy," *Journal of Hygiene* 7 (1907), 634-71; L. G. Wilson, "The clinical definition of scurvy and the discovery of vitamin C," *Journal of the History of Medicine and Allied Sciences* 30 (1975), 40-60.

antiscorbutic factor.

The first significant development came from the laboratory of the Hungarian biochemist Albert Szent-Györgyi. He isolated hexuronic acid, later renamed ascorbic acid, a reducing compound present in crystalline form in oranges, lemons, cabbages, and adrenal glands.[33] In 1932 chemists W. A. Waugh and C.G. King at the University of Pittsburgh published their groundbreaking paper "The Isolation and Identification of Vitamin C" in which they published a photograph of vitamin C crystals.[34]

The consumption of fresh fruit and vegetables, particularly citrus fruit and broccoli, was shown in the prevention and cure of scurvy. Vitamin C is also found in liver and many varieties of fatty fish as mentioned earlier. Therefore, scurvy is rarely endemic in Inuit populations. The total body pool of ascorbic acid in a 70 kilogram man is estimated at about 1.5 grams and can be attained in most people by the sustained daily intake of 60 to 100 milligrams. A daily intake of 10 milligrams vitamin C results in a steady-state body pool of about 350 milligrams and no signs of scurvy unless the pool falls to below 300 milligrams.[35] When vitamin C is depleted there is a comparatively rapid loss of vitamin C due to a continuing catabolism of the vitamin and a urinary excretion of its breakdown products.

Functionality

Vitamin C has a host of normal biological functions, primarily acting as a coenzyme for the normal function of cells and its subcellular structures such as the synthesis of carnitine, a molecule essential for the transport of fat to the energy storehouse organelles, mitochondria. Vitamin C also appears to be involved in the metabolism of cholesterol to bile, thus implicated in the incidence of the formation of gallstones. In ordinary metabolism, vitamin C serves as an acceptor and donator of hydrogen. Vitamin C assists in the facilitation of iron and calcium absorption and it is essential for the body's utilization of folacin (folic acid). Vitamin C also functions to assist in the synthesis of neurotransmitters that allows nerve impulse to travel between nerve axons. It also plays a role in the synthesis of norepinephrine that is critical to brain function and is known to affect mood. Therefore dietary deficiency of the vitamin can produce is scurvy, but also depression, hysteria, and hypochondriacal symptoms. The psychiatric manifestations may explain many old sailor's tales about the horrors of "the scurvy."

The most the familiar function as related to connective tissue physiology is production of collagen. This protein maintains capillary integrity and intercellular cement substance promoting the healing of wounds, bruises, bone fractures, hemorrhages, and bleeding gingiva. Vitamin C also has been found to reduce susceptibility to infections.

33 A. Szent-Györgyi, "Observations on the function of the peroxidase systems," *Biochemical Journal* 22 (1928), 1387-1409.

34 W. A. Waugh and C.G. King, "The isolation and identification of vitamin C," *Journal of Biological Chemistry 97* (1932), 325-31.

35 A. Kallner, "Vitamin C — man's requirements," in J. N. Counsell and D. H. Hornig, eds., *Vitamin C -ascorbic acid* (London, 1981).

Vitamin C is also a highly effective antioxidant that can protect molecules in the body, such as proteins, lipids, carbohydrates, and nucleic acids from damage by free radicals, pollutants and toxins. Vitamin C may also act as an agonist or regenerator for other antioxidants such as vitamin E. In addition there is evidence that vitamin C also influences the formation of connective tissue by modifying the nature and formation of the extracellular matrix molecules and indirectly proteoglycan formation.[36]

The simple means of prevention of scurvy, its pathophysiology and the mechanism(s) of action of vitamin C are now fairly well understood. What has been largely forgotten is that this transient occupational disease of sailors with severe and debilitating physical and mental appearances had a significant impact upon a variety of maritime endeavors and events for approximately four hundred years.

A Very Brief Overview of Scurvy's Affect on Maritime History

In an extensive work about the history of the scurvy David Harvie made an observation concerning the men who actually treated the sick seamen. He said, "The conquest of scurvy by ill-resourced and professionally despised naval surgeons is one of the great triumphs of eighteenth-century medicine. The men who went to sea as naval surgeons were not paragons; these often were ill-trained men practiced their craft in the most difficult of physical circumstances … Most doctors at sea were known as naval surgeons, and they did not enjoy high standing. The usual route into naval medicine was for a relatively untrained man to enlist as a surgeon's mate, to gain promotion by observation, imitation and — if he was lucky — a touch of patronage."[37] Unfortunately this produced the all too true awkwardly rhymed adage:

> Some fell by laudanum, and some by steel,
> And death in ambush lay in every pill.[38]

When major European powers were at war, large fleets roamed the seas or were stationed off foreign stations for long periods of time. Supplying (victualing) the widely scattered vessels with fresh food was a huge problem. From 1774 to 1780 the Royal Navy recruited 175,990 men, an impressive number on a population base of about 10 million British citizens. From these personnel 1,243 (0.7 percent) were recorded as killed in action or died from wounds, 18,541 (10.5 percent) died from disease [about two-thirds from scurvy] and 42,069 (24 percent) listed as deserted on the muster books.[39] Scurvy was a serious problem in Britain's Channel Fleet, but it was a disaster in its West Indian fleet. Admiral George Brydges Rodney's vessels in the West Indies were crippled with

36 B. Peterkofsky, "Ascorbate requirement for hydroxylation and secretion of procollagen: Relationship to inhibition of collagen synthesis in scurvy," *American Journal of Clinical Nutrition* 54 (1991), 1113S-27S.

37 D. I. Harvie, *Limeys: The Conquest of Scurvy* (Phoenix Mill Thrupp, UK, 2002), 4.

38 Ibid., 58.

39 N. Miller, *Broadsides: The Age of Fighting Sail, 1775-1815* (New York, 2000), 60.

nearly 3,000 cases of the disease.[40] Rodney's Physician to the Fleet Gilbert Blane noted that fresh vegetables, particularly citrus fruits, prevented and cured the disease. For storage, the physician advised that two quarts of French brandy be added to five gallons of citrus juice and stored in casks for later distribution.[41]

British sailors impressed into service were rarely allowed the freedom of shore leave. Thus scurvy became a major problem at sea. The British attempted to supply a daily ration of three-quarters of an ounce of limes and lemons to their sailors starting in 1795. From 1795 to 1814, Admiralty records indicate that 1.6 million gallons of lemon juice was given to their sailors.[42] This was how the term "Limey" became applied to British seamen. Finally, the impact upon the Royal Navy is perhaps best summarized by Lind who noted that "[Despite] our fleets and squadrons . . . scurvy alone, during the last war, proved a more destructive enemy, and cut off valuable lives, than the united forces of the French and Spanish arms."[43]

Scurvy had an impact on the procurement of crews to man America's nascent navy. A 1798 recruitment broadside issued by Captain Samuel Nicholson of the frigate *Constitution* said, "None will be allowed to enter this honorable service, but such as are well organized, healthy and robuss [robust]; and free from scorbuttic and consumptive affections."[44] This became a problem for this famous vessel when its second captain, Silas Talbot, noted in the ship's log on 6 June 1800 that thirty men reported sick: "their chief diseases are the fever and scurvy, the latter of which daily increases."[45] Citrus was not regularly provided to American warships until about the outbreak of the War of 1812. The reason that this simple preventive medicine measure was not adopted is not clear, but was likely one of limited supply of the fruit and no known alternatives.

Although a cure for scurvy became widely known, it continued to plague some seamen well into the latter part of the nineteenth century. Many of the forty-niners who sailed around South America to California and a few years later to the Alaskan gold rush contracted scurvy en route. A forty-niner made the following journal entry: "A great many persons from the long voyages around Cape Horn arrived [in California], sick with the scurvy, owing to want of vegetables at sea, most of whose systems underwent a change to become acclimated to the country; some seriously and others more mildly."[46] The government sponsored Goode fisheries industry report of 1887 noted that scurvy appeared to be the most common disease among whaling vessel crewmen."[It] usually begins to show itself about six to eight months after the vessel has left home port. [This

40 C. C. Lloyd, ed., *The Health of Seamen: Selections from the Works of Dr. James Lind, Sir Gilbert Blane and Dr. Thomas Trotter* (London, 1965), 142.

41 Ibid., 168-89.

42 C. C. Lloyd and J.L.S. Coulter, *Medicine in the Navy 1200-1900. Vol. III, 1714-1815* (Edinburgh, 1961), 320-4.

43 J. Lind, *A Treatise of the Scurvy*, (Edinburgh, 1753), 5.

44 J. W. Estes, *Naval Surgeon* (Canton, 1998), 34.

45 Ibid., 43.

46 D. Knower, *The Adventures of a Forty-niner* (Mystic, 1894), 111.

disease caused] swelling up and softening of the limbs of the sufferer. . . the limbs turning black and shriveling in size . . . often leav[ing] . . . the victim lame for life."[47]

In summary, the search for the cure of scurvy, particularly at sea, is a story that mixes groundbreaking achievement with medical officialdom producing bureaucratic stasis — an interlinking of science with medical politics and a smattering of parliamentary politics that found its resonance in the perversity of officialdom. This is a complex tale of a terrible scourge, one specific disease that profoundly affected the maritime history of the western world.

47 G. B. Goode, *The Fisheries and the Fishing Industry of the United States* (Washington, 1887), sec. IV: 93.