Sailors' scurvy before and after James Lind – a reassessment

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Scurvy is a thousand-year-old stereotypical disease characterized by apathy, weakness, easy bruising with tiny or large skin hemorrhages, friable bleeding gums, and swollen legs. Untreated patients may die. In the last five centuries sailors and some ships' doctors used oranges and lemons to cure and prevent scurvy, yet university-trained European physicians with no experience of either the disease or its cure by citrus fruits persisted in reviews of the extensive but conflicting literature. In the 20th century scurvy was shown to be due to a deficiency of the essential food factor ascorbic acid. This vitamin C was synthesized, and in adequate quantities it completely prevents and completely cures the disease, which is now rare. The protagonist of this medical history was James Lind. His report of a prospective controlled therapeutic trial in 1747 preceded by a half-century the British Navy's prevention and cure of scurvy by citrus fruits. After lime-juice was unwittingly substituted for lemon juice in about 1860, the disease returned, especially among sailors on polar explorations. In recent decades revisionist historians have challenged normative accounts, including that of scurvy, and the historicity of Lind's trial. It is therefore timely to reassess systematically the strengths and weaknesses of the canonical saga.

INTRODUCTION

Long intercontinental voyages began in the late 16th century and were associated with scurvy that seamen discovered could be cured and prevented by oranges and lemons. However, most physicians ignored this lay therapy in favor of ancient theories and useless polypharmacy. Public recognition of the value of citrus fruits came from thoughtful 18th century ships' surgeons, especially James Lind whose 1753 *Treatise of the Scurvy* inspired his successors to persuade the British admiralty in the mid-1790s to abolish naval scurvy with juice of European lemons.[1–7]

Lind's detailed account of his 1747 prospective controlled therapeutic trial has been regarded as an iconic event in the history of clinical science. However revisionist historians have cast doubt on many aspects of this Lind/scurvy conquest story. They proposed that Lind's trial was not the first, his science was irregular, his patients do not appear on the ship's sick list, his choice of remedies was improper, and his inspissated juice was useless. "Scurvy" was dismissed as a catch-all term, and its morbidity and mortality were said to have been exaggerated. Revisionists have disputed the role of scurvy in the defeat of Napoleon, and its responsibility for deaths in the Antarctic. The admiralty has been censured for the 40-year lag in introducing routine lemon juice, and for later substituting ineffective lime juice. I have therefore summarized the complex history of the conquest of scurvy in order to scrutinize in 21 interrogative sections the strengths and weaknesses of the canonical saga.

Scurvy is a particularly stereotypical disease characterized by apathy, weakness, easy bruising, tiny or large skin hemorrhages, friable bleeding gums, and swollen legs. Untreated patients may die. Scurvy is due to a deficiency of the essential food factor ascorbic acid, vitamin C, that, in adequate quantities, completely prevents and completely cures the disease, so that it is now rare. Thus,there should

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be little to discuss, but the human history is complicated and involves centuries of misunderstandings.

WHEN DID SCURVY BECOME A MAJOR PROBLEM?

Northerners in Europe and America may have suffered for centuries from land scurvy and treated it with cresses and spruce leaves. Sailors' scurvy probably dates only from the era of long sea voyages when voyagers were away for so many weeks as to deplete the limited body stores of ascorbic acid while they had no fresh foods.[8,9]

The major outbreaks came after ocean voyages to Asia (such as Vasco da Gama's in 1497[10] with relief by citrus fruits[11]), the Americas (such as Jacques Cartier's in 1536[12] with relief by spruce bark and leaves[13,14]) and West Africa (in 1553 with relief by oranges and lemons[15]). The Dutch imported citrus fruits from Spain and while one physician in 1564 used them successfully,[16] other Dutch physicians in the 16th century treated scurvy only with conventional purges and inunctions,[17] at a time when Mexicans cured sailors with scurvy (*escorbuto*) from Spain with lemons (*limon*), oranges (*naranja*), and limes (*lima*).[18,19]

Thus, the first Dutch East Indies Fleet sailed in 1595 with 249 men and returned in 1597 with only 88.[20] The 1598 fleet took lemon juice, grew horseradish and scurvy-grass (a corruption of "scurvy-cress") on board, and lost only 15 men. Sir Richard Hawkins in 1590 bought hundreds of oranges and lemons in Brazil for his men, perhaps based on his experience as a prisoner-of-war in Spain: "that which I have seene most fruitful is sower oranges and lemons . . . I wish that some learned man would write of it, for it is the plague of the sea, and the spoyle of mariners. Doubtlesse, it would be a meritorious worke with God and man, and most benificiall for our countrie; for in twenty yeares, since that I have used the sea, I dare take upon me to give accoumpt of ten thousand consumed with the disease."[21]

Too many "learned men" (physicians/scientists) did write about scurvy for the next 450 years, but they only obscured the facts obvious to any experienced sailor. However, English surgeons such as William Clowes (1540–1604) were pragmatic using plentiful berries, vegetables, and scurvy-grass (*Cochlearia officinalis*), now known to contain as much ascorbic acid as orange juice.[14,22–24]

DID LANCASTER PERFORM THE FIRST CONTROLLED SCURVY TRIAL?

In 1591–1594 James Lancaster (fl.1591–1618) made the first of many long sea voyages to Brazil and the East Indies.[25] It was only on the third voyage of 1601–1603 that his flagship *Red Dragon* carried lemon juice, recommended by Sir Hugh Platt, presumably aware of Hawkins success with this treatment. Lancaster gave this juice to each of his 202 sailors "as long as it would last, three spoonfuls every morning fasting."[26] His other three ships had no lemon juice. Samuel Purchas (1577–1626) reported: "By this means the General cured many of his men and preserved the rest: so that in his ship he had not so many sick, nor lost as many men as they did."[27]

Keevil, the medical historian of the British Navy, made several claims for Lancaster's voyage, based on Purchas's conclusions. Keevil credited Lancaster "with using lemon juice both for the prevention as well as cure of scurvy, and this one voyage should have established the method of avoiding it in all ships for ever. Even the accident of only the flagship having lemon juice was of scientific value in providing a controlled experiment but the whole experience was soon lost."[28]

Unfortunately, we lack precise numbers of those with scurvy in each ship, but it is possible to calculate their mortalities. Lancaster's fleet sailed on 20 April 1601 and by 1 August "very many men were fallen sicke of the scurvey in all our ships". By the time they arrived at Table Bay, 105 of the 480 sailors had died, 80 (76%) of scurvy.[27] The fleet called at Madagascar for oranges and lemons and then sailed to Sumatra. Before they left there on 11 November 1602, the mortality rates on the four ships were as follows: *Dragon* 66/202 (33%), *Hector* 37/108 (34%), *Ascension* 38/82 (45%), and *Susan* 39/88 (44%), for a total of 180/480 (38%) deaths. Thus, contrary to Purchas's assertion, the four death rates were similar. And, since scurvy was responsible for three-quarters of the deaths, it seems I was wrong to suggest in a previous publication that there were no deaths on the *Dragon*.[29] Nor was Keevil correct in implying that Lancaster's "trial" was a controlled experiment, or that the voyage proved lemon juice had "scientific value" in preventing scurvy.

Nevertheless, Lancaster regarded his lemon juice a success and persuaded the East India Company to issue this juice on the voyages of 1604 and 1607, but this did not happen consistently. There was a special order for it in 1627,[30] but on the juiceless 1678 voyage, half the ship's crew were disabled by scurvy and then cured by fresh limes and oranges. Platt also interpreted the result of Lancaster's use of his lemon juice as "an assured remedy in the scurvy". Platt was one of the first to address the problem of the loss of efficacy of citrus juices with time, and recommended "the help of a sweet olive oil supernatant . . . lest it lost much of his first manifest nature, which it has whilst it was contained within its own pulp and fruit".[31]

WERE CITRUS FRUITS USED IN VOYAGES BEFORE LIND?

François Pyrard's ship left St Malo on 18 May 1601 without lemon juice and landed in Madagascar on 11 February 1602. "Such as were sick of the scurvy – a great number" were not treated with fruit and almost all died. There, they met a Dutch ship that had lost none of its men[32] (presumably because the Dutch ships stocked lemon juice). By the end of the voyage Pyrard recommended that "it is especially necessary before setting out to make provision of orange and lemon juice in order to their protection against this scurvy".[33]

When, in 1611, the new Lord Governor of Virginia arrived in Jamestown he had developed scurvy and promptly shipped himself to the West Indies where "I found help for my health and my sickness assuaged, by means of fresh diet, and especially of oranges and lemons, an undoubted remedy and medicine for that disease, which lastly, and for so long, had affected me."[34]

John Woodall (1556–1643), the first surgeon general of the East India Company, and like Clowes a surgeon to St Bartholomew's Hospital, London, recommended in his 1617 textbook, *The Surgions Mate*, "The Chirurgeon or his Mate must not faile to perswade the Governour or Purser in all places where they touch in the Indies and may have it, to provide themselves of juice of Oringes, limes or Lemons." Woodall held that "where a disease mostly raigneth, even there God hath appointed the best remedies for the same grief, Lemmons, Limes, Tamarinds, Oringes'. He claimed that "there is a good quantitie of Juice of Lemmons sent in each ship out of England by the great care of the Marchants [and concluded] The use of the juyce of Lemmons is a precious medicine and well tried, being sound and good; let it have the chief place, for it will deserve it".[35,36]

Dr. John Hall, Shakespeare's son-in-law, claimed to cure scurvy by brewing a beer or ale from "Scorbutick herbs, *viz*: scurvey grass, water cresses and brook lime".[37] Similarly Sydney Humphreyes in the middle of the 17th century wrote in his recipe book a treatment for scurvy: "Take two pintes of water, and one of white wine, boyle them together, then put to it, halfe a pinte of the juice of Scurvie grasse, & a quarter of a pinte of the juice of water Creasus, & as much of the juice of brooke lime, & a little juice of oranges, and for drinke halfe a pinte every morning".[38] Another textbook for mariners, by another Governor of Virginia in 1626, recommended lemon juice for scurvy,[39] and by the middle of the century botanical texts agreed with this advice.[40]

Oranges, lemons, and their juices were certainly sold in England in the 17th century. The oranges were imported to London from Portugal via the Netherlands. There is a nursery rhyme that begins "Oranges and lemons | ring the bells of St Clements", perhaps because the church of St Clement's Eastcheap, near the Thames Street wharves at the foot of London Bridge, was en route from these docks to Covent Garden market. Moreover, Nell Gwyn, the future mistress of King Charles II, had sold oranges at the Drury Lane Theatre in 1665, and Pepys recorded his enjoyment of drinking one pint of orange juice in 1669.

However, in the winter of 1620 the *Mayflower* lost 50 of 102 on board, mostly from scurvy, during its 56-day voyage. In 1628, Admiral Fleming's Swedish squadron off the Polish coast had two-thirds of the 115 men dead or dying from scurvy with only 19 fit for work; he then obtained 200 lemons for them.[41]

At the end of the 17th century, junior sea surgeons were informed that scurvy was rare in southern countries such as Spain and Italy because they eat "good store of green Herbs and Fruit." They were therefore advised that "where the succulent Herbs and Roots and fruits, as lemons and oranges, are freely taken; there is no fear of the Scurvy".[42] For 1696, OED cites *Antiscorbuticks* as a new word for medicines against the scurvy.

Yet orthodox physicians, such as Thomas Willis,[43] Gideon Harvey,[44] Boerhaave,[45] Meade,[46] and Cullen,[47] wrote copiously and learnedly about scurvy, but without any maritime experience, simply listing the many standard theories of the cause of scurvy, and the many standard medical treatments such as bleeding, purging, and polypharmacy. Many of them mentioned treatment with oranges and lemons but without making it clear that sailors and ships' surgeons had long been satisfied that citrus fruits were specific prophylactics and cures for scurvy.

Some academic dissertations did formulate a unitary etiology, and thus a rational and successful therapy. In 1721, Johann Kramer, physician to the Hungarian army, advised "Seek the cure of scurvy neither in the armamentarium of the physician nor in the apothecary shops . . . On the other hand, employ fresh vegetables, the juice of fresh antiscorbutic plants, oranges and lemons or the juice of those fruits preserved in sugar; in this way without other means you will be able to overcome this terrible disease."[48] In 1734, Johann Bachstrom of Leyden (1686–1742) was one of the first to declare land scurvy and sea scurvy to be identical diseases and to attribute their cause to a deficiency of fresh vegetables, and therefore curable by fresh herbs, fruits, and berries.[49]

William Cockburn (1669–1739), who had been medical adviser to the fleet and physician to the Blue Squadron, successfully treated with fresh vegetables (cabbage, carrots, colewort, and turnips) 100 sailors with scurvy – "perfect moving skeletons" – put ashore at Torbay in 1695.[50,51] Cockburn was so successful in 1701 in advising the Navy to buy lemons that their price at Billingsgate Market rose above £4 per chest.[52] The priva-

teer Dr. Thomas Dover sailed with Captain Woodes Rogers around the world from 1708 to 1711 and although they bought citrus fruit at the few ports where they stopped, they still had scurvy in the months-long intervals.[53]

Meanwhile, in Spain and Mexico, the sovereign remedy for scurvy remained lemon juice, and its preparation and storage were described in detail in 1712.[54] Perhaps the most physician-induced disaster was Commodore Anson's circumnavigation of 1740–1744. The admiralty ignored the centuries of experience of seamen and instead took advice from the College of Physicians and supplied Anson's ships with elixir of vitriol (sulphuric acid, alcohol, sugar, and spices) as a substitute for acid fruits on the concept that the efficacy of citrus fruits was related to their acidity. Anson's six warships and two supply ships sailed with 1854 men. One ship and 188 men returned; 997 of the 1415 deaths were from scurvy.[55]

WHAT DID JAMES LIND DO AND WRITE?

There is a vast literature on Lind (1716–1794). Suffice it to say Lind reported the first controlled prospective therapeutic trial.[56] Lind was born in Edinburgh, apprenticed at age 15 to a surgeon, joined the Navy as a surgeon's mate in 1739, and for 8 years was almost continually at sea, in the Channel, the Mediterranean, and the West Indies. He became surgeon on HMS *Salisbury* before it sailed for six Channel patrols from December 1746. On Lind's sixth patrol, in the Bay of Biscay, he described how on 20 May 1747, 8 weeks after leaving port, he chose 12 typical cases of scurvy of similar severity and placed them in the same sick bay on the same diet. Five of the six pairs had for 2 weeks either a quart of cider a day, 25 drops of elixir of vitriol three times a day, two spoonfuls of vinegar three time a day, half a pint of sea-water every day, or a nutmeg-size purgative electuary three times a day; none were cured. The sixth pair had two oranges and one lemon every day for 6 days only; one of the pair became fit and then the other. By the end of the voyage on 16 June, 80 of the complement of 350 were more or less afflicted by scurvy or by a new malady such as gastroenteritis.

Lind then left the Navy in 1748 and returned to Edinburgh where he took his MD by thesis, practiced as a physician, and in 1750 was elected fellow (and later treasurer) of Edinburgh's Royal College of Physicians,[57] which now houses a library of his work (www.jameslindlibrary.org). He probably devoted much of his first 5 years in Edinburgh to reading the literature on scurvy in the college library, and writing and publishing in 1753 his *Treatise on Scurvy* based on "a paper for the Society of Surgeons of the Royal Navy, with a design of having it published by them". He then wrote in 1757 *An essay on the most effectual means of preserving the health of seamen in the Royal Navy*, had a paper read before the Royal Society in 1762 on producing "purest elementary water" by distilling sea water, read *Two papers on fevers and infections* before the Philosophical and Medical Society in Edinburgh in 1763, and published in 1771 *An essay on diseases incidental to Europeans in hot climates*. He dedicated his *Treatise on Scurvy* to Lord Anson, who perhaps recommended Lind's appointment in 1758 as chief physician to the Royal Naval Hospital, Haslar.

WAS LIND'S REVIEW OF THE LITERATURE ON SCURVY COMPREHENSIVE?

In his *Treatise* Lind abstracted the contents, and provided a chronological index, of 57 books on scurvy published between 1534 and 1753,[1] five more in his second edition,[2] and 12 more in the third edition.[3] However, it is impossible to know how many of these he could have read while in the Navy between 1739 and 1748. On page vii of his preface he promised "to remove a great deal of rubbish". Milne and Chalmers counted the number of times each of Lind's six treatments were mentioned in the *Treatise:* oranges and lemons (117), vinegar (29), vitriol (29), sea water (19), cyder (16), and nutmeg (2).[4] In his chronological abstracts, Lind clearly stated Kramer and Bachstrom's unitary fresh vegetables hypothesis for cause and cure of scurvy. However, his own chapters on the causes and cures of scurvy are full of obscure and uncritical concepts, and one is left with his ideas that sea scurvy was due to excess perspiration, could be prevented by ventilation, and that many remedies could be used as well as citrus fruits and cresses.

Moreover, as Keynes pointed out,[58] Lind failed to scrutinize Woodall's 1617 publication *The Surgions Mate*[37] with its clear recommendation of equipping ships to the East Indies with lemon juice to prevent scurvy. Nor did Lind cite books by other authors recommending citrus fruits such as Farfan,[18,19] Hawkins,[21] Clowes,[22] Smith,[41] Ferrari,[42] Moyle,[44] and Esteyneffer,[56] presumably because they were not then in the library of the Edinburgh College.[59]

WAS OR IS "SCURVY" A STEREOTYPICAL OR HETEROGENOUS DISEASE?

Lind carefully noted these authors' descriptions of the clinical features of the illnesses they called "scurvy", both the land and sea varieties. Most of these descriptions were concordant and compatible with subsequent and today's normative texts, and with the precise symptoms and signs produced in human volunteers by an ascorbic-free diet, and cured by ascorbic acid. However, when Lind summarized Gideon Harvey's 1675 classification of mouth, leg,

and joint scurvy,[44] he did not comment that Harvey never referred to what he called "scurvy" as occurring in seamen. To my reading, Gideon Harvey's descriptions seem instead to be those of venereal diseases or the results of their treatments with mercury and antimony, as recounted in his earlier books.[60,61] Another anomaly was the characterization by Archibald Pitcairne (1652–1713) of scurvy as a "Hypochondrial Melancholy".[62]

In 2004, Rodgers, the official historian of the British Navy, referred to scurvy as "a disease whose name was used by doctors as a catch-all term for anything they could not identify or cure".[63] This put-down sentence is not justified, nor were the Mettlers in their 1747 *History of Medicine* justified in claiming in an equally sweeping statement, "In the seventeenth century the most that could be said for 'scorbitus' was that it was a diagnosis applied to obscure digestive complaints accompanied by cardiac palpitations, vomiting, hiccup, flatulence, subcutaneous hemorrhage, mental depression, and other neural disorder".[64]

The surgeons or surgeons' mates of the world's navies and armies seem to have had no difficulty in learning to diagnose scurvy from its typical clear-cut features, well described in their standard texts. It is remarkable in the many descriptions of privations, both at land and sea, characteristic specific clinical features are recognizable today as those of scurvy, and only rarely of other diseases such as those caused by deficiencies of other vitamins (A, B, etc). Indeed, Lind cited the statements of other highly experienced clinicians. Kramer, who had seen more than a thousand cases in Hungary, wrote: "The appearances all are constantly uniform",[65] and Vander Mye at Breda stated: "The scurvy is not a hodge-podge or complication of various different diseases, but is itself a simple identical malady."[66] Moreover, most of those diagnosed then with scurvy responded rapidly, within hours or days,[67] when given what we now know to be effective antiscorbutics, unlike the slower responses to treatments of other known avitaminoses. Hair's studies of diaries of English sailors and surgeons voyaging to West Africa revealed how scurvy was readily diagnosed and distinguished from febrile and diarrheal disorders.[68]

Lind was well aware of the putative misdiagnosis of scurvy. "Some will perhaps say that these fruits have often been used in the scurvy without success; as appears from the experience of physicians, who prescribe them every day in that disease at land. And here we may again observe the fatal consequences of confounding this malady with others. Legions of distempers (according to Willis and others) very different from the real and genuine scurvy, have been classed under its name: and because the most approved antiscorbutics fail to remove such diseases, hence we are told by authors (Boerhaave and many others) that it is the masterpiece of art to cure it . . . So that nothing can be more absurd, than to object against the efficacy of these fruits in preventing and curing the real scurvy, because they do not cure very different diseases".[69]

Although sea scurvy was minimal in the 19th century, lack of fresh vegetables, especially in winter, made soldiers' scurvy rife – "that scourge of armies, in some of its protean forms".[70] In 1820, one US military post of 1016 men had 895 sick with 503 cases of scurvy of whom 168 died. In the nomenclature of the Civil War, scurvy was classified in class I, order III, dietic. It was logistically impossible to provide fresh food or citrus fruits or juices to prevent scurvy and there were 30,714 cases (383 deaths) in white troops and 16,217 cases (388 deaths) in the colored.[71] An outbreak in the Army of the Potomac was cured by 1500 boxes of lemons.[72] Even in the notorious Confederate camp in Andersonville, Georgia, holding an average of 19,453 Northern prisoners with 46,974 cases of disease (7126 deaths) it was possible to diagnose 16,722 cases of dysentery and 9501 of scurvy (266 deaths).[73] Similar outbreaks occurred in the British and French armed forces in the Crimean War.

Obviously, on land, civilian and military food shortages could, in theory, produce multiple deficiencies of calories, carbohydrates, fats, proteins, and accessory factors such as vitamins. However, only a few of the malnourished described in the several essays by Watt et al. in the 1980 National Maritime Museum international symposium did have vitamin A and B deficiencies, sometimes in addition to scurvy.[74]

Vitamin A deficiency causes nyctalopia (night blindness) that was extraordinarily rare, because this vitamin is stable and resists boiling and was present in high concentrations in the animal offal of the British Naval portable soup. During Anson's 1740–1744 circumnavigation, the master of the *Wager* became night-blind and wrecked his ship on Tierra del Fuego.[75] Surgeon Telford reported to Blane that four sailors had evening blindness in 1781 on HMS *Alcide* off Barbados. Two had "scurvy in a high degree, one of them slightly, and the other seemed entirely free of it".[76] Blane had also been told of such nyctalopia in the garrison at Gibraltar and commented that this "remarkable symptom sometimes attendant on this disease which had escaped the notice of authors". In later centuries, nyctalopia occurred aboard the US Navy's *Columbia* on its round-the-world voyage of 1838–1840, occasionally in the US Civil War,[77] and rarely in German sailors in World War II.[78]

Vitamin B deficiencies of thiamine, nicotinic acid, and riboflavin would have been most unlikely, but there was one report of thiamine-deficient beriberi aboard a German cruiser in 1915.[79]

Diarrheal diseases were common in armies and navies but were not symptoms of scurvy. Diarrhea was

usually a symptom of dysentery, and could also occur in tropical sprue. Diarrhea might precipitate scurvy by alkalinizing the intestine and thus destroying ascorbic acid; in turn, those prone to scurvy could be more susceptible to infections such as dysentery.[80]

WAS LIND'S TRIAL THE FIRST AND ITS DESIGN SCIENTIFICALLY CORRECT?

In 1975, Hughes (correctly) pointed out that there had been therapeutic trials before Lind (who had not claimed any priority), but went on "to point out Lind's sins of omissions".[81] Hughes classified Lind's trial as "controlled empiricism" rather than "rationally-derived experimentation", so that "Lind's . . . demonstration . . . was an essentially fortuitous happening, and scientifically a non-significant one".[82] I do not agree that a therapeutic trial must be based on pathophysiological theory; all that is necessary scientifically is the conventional construction of a refutable hypothesis followed by test and publication. Carpenter argued similarly: "Certainly, it should be a mark of respect, rather than the reverse, to treat Lind's work as being worthy of detailed analysis".[83]

WAS LIND'S CHOICE OF REMEDIES TO CURE SCURVY VALID?

Hughes criticized Lind's six remedies "selected empirically from those currently favored by ships' surgeons".[84] They were not; they were chosen from those recommended and published by medical authorities. Lind selected his five chemical remedies as representative of advice given by physicians to the Royal Navy. Glauber and Boerhaave had advocated acids, and "the college of London, when consulted by the Lords of the Admiralty" recommended two acids, elixir of vitriol and wine vinegar.[85]

Dr. John Huxham had recommended apples from a cask, lemons and oranges wrapped in flannel, or a mixture of lemon juice and rum, with or without 3-month-old rough cider (1 pint daily), as well as beer and water.[86] Huxham was so confident in his regime – "What will cure will prevent" – that he communicated his proposal to several captains and surgeons of the Men of War, and afterwards published it in the *General Evening-Post* and the *Gentleman's Magazine* in October 1747. Lind had previously tested that dose of sea water for 2 weeks and found no benefit.[87,88] Today's investigators try to ensure that their patients' illnesses are all at a similar stage of the disease, but Lind wrote that he had allocated "two of the worst patients, with the tendons in the ham rigid, (a symptom none of the rest had)" and put them "under a course of sea water".[89]

Hughes suggested that Lind should instead have tested lay remedies such as John Wesley's – nettle juice, cresses, mustard, and goose and scurvy grasses – all of which Hughes had analyzed and found to contain adequate ascorbic acid. Unfortunately, Hughes consulted the 1791 23rd edition of Wesley's *Primitive Physick*[90] that Lind could not have read in May 1747. Nor could Lind have read Wesley's first edition of June 11, 1747, that recommended turnips for 1 month, milk for 6 months, tar-water for 3 months, horseradish, fumitory, docks, and rue.[91]

Hughes also deplored Lind's use of oranges and lemons because he was aware of their reputed efficacy,[92] but I do not consider the inclusion of a probable positive control as unreasonable, especially because the naval authorities had never recommended citrus fruits to treat scurvy.

DID LIND'S *ROB* PRESERVE THE EFFICACY OF LEMON JUICE?

Lind was well aware that it was impractical to carry citrus fruits on long sea voyages because, as Woodall noted, "oranges and lemons are liable to spoil", as indeed would lemon juice.[35] Lind therefore devised a system of almost boiling purified citrus juice, so that 24 oranges or lemons were reduced to a few ounces, and he claimed the juice of dozen fruits put into a quart bottle could be effective for several years.[93]

Hughes (correctly) joined others in asserting that Lind's *rob* (from the Arabic *robb* and Persian *rob* = fruit syrup[94]) was later shown to be ineffective in preventing scurvy (now known because he had boiled the heat-labile ascorbic acid), and (correctly) that Lind was unscientific in presenting no evidence for his *rob*, merely "by my own experience", "the most incontestable experience", "remains good for several years", and "preserving their virtues for years".[95] Lind, in further editions of his book, maintained his belief in the efficacy of what was named in his 3rd edition as *rob*, until in the 1778 edition of his *Health of Seamen* he reformulated his syrup of lemons. Sound lemons are squeezed, the juice is filtered (but not boiled), put into small bottles no bigger than a pint, and olive oil poured into the neck of the bottle that is then corked and sealed – the precise system devised by Platt in 1607.[31]

The Mettlers *History of Medicine* stated, "James Lind could never have cured any real cases of scurvy with the boiled and evaporated orange syrup he recommended so highly. It is difficult to believe that Lind was an absolute fraud, and we can only conclude that he embroidered his account in order to achieve greater elegance".[64]

DID LIND PERFORM HIS EXPERIMENT IN MAY 1747?

In 2003 Graham Sutton (admirably) searched HMS *Salisbury's* original papers, both the captain's log and the

separate roll-call, part of the pay/muster roll, for May 1747.[96] "However the weekly roll-call shows at most one or two, and usually none, as sick during this entire voyage". Today's journal editors might wonder whether Lind's recollection in 1753 was reliable. To perform his prospective trial in 1747, Lind would have needed to take on board the appropriate quantities of the six test medicaments for the 14 days, yet he had only enough oranges and lemons for 6 days. Perhaps this therapeutic trial had not occurred in the precise format of the *Treatise*?

Sutton suggested one explanation: "Presumably the Navy had a harsh definition of sickness, and accepted scurvy just as we might accept a 10% prevalence of the dietary disease of obesity." However, the Royal Navy's definition of "sick" was unambiguous: "Ships captains set their threshold for sickness at the level where a man could no longer stand his watch, not at the level where his health was impaired".[97] Yet Lind described placing his 12 cases in the sick bay where they would hardly have been available to stand watch. Did Lind not discuss the results of his experiment with his chief, whom he praised as "that great and humane commander the Hon. Captain Sir George Edgcumbe . . . whose generous liberality . . . daily supplied . . . the scorbutic people . . . with fresh provisions from his own table"? Edgcumbe, who later became an admiral and a viscount, was possibly one of those sea captains who did not want his sailors to be recorded sick. Nevertheless, in 1762, Lind dedicated the second edition of his *Health of Seamen* essay to him. In 1754, the *Salisbury*, under a different captain, in the East Indies was free of scurvy because Lind's colleague Dr. Ives issued citrus juice.

I find it curious rereading Carpenter's textbook on scurvy how bitter the scurvy controversies have been over the centuries. I do not believe that Lind was a fraud. He was a respected and successful physician in Edinburgh, awarded its MD, fellowship of its Royal College of Physicians (and then its treasurer), was probably a member of its Society of Naval Surgeons, and his papers were read at both the Royal Society of London and the Philosophical and Medical Society in Edinburgh. He wrote two other classics, one in 1757 on naval hygiene,[98] the other in 1768 on tropical diseases,[99] and his works were highly regarded by his successors such as Trotter and Blane. Nevertheless, it is curious that after leaving the navy in 1748 and being awarded his Edinburgh MD he did not submit a thesis on his recent clinical trial on scurvy; instead, he wrote about venereal diseases.

Lind's account of his 1747 experiment has been accepted ever since 1753 as an historical event, but now I am suggesting some skepticism, especially because another report, also from Edinburgh, of a well-designed prospective therapeutic trial, has now been queried by Lisa Rosner, the biographer of Lesassier Hamilton.[100] Hamilton, a member of a family dynasty of distinguished Edinburgh doctors, based his successful 1816 MD thesis on a three-arm trial of bloodletting in 366 consecutive admissions of soldiers to the Elvas hospital in 1809 during the Peninsular War. By not letting blood, he lost four cases in Elvas and his colleague, Mr. Anderson, lost one, whereas a third surgeon did bleed his patients and lost 35.[100] "Hamilton was not entirely reliable . . . [and his] comprehensive diaries [78 notebooks from 1803–1830 and 31 small notebooks during the Peninsular War 1809–1814] do not include any mention of a bloodletting in Elvas. Did the trial take place?"[101,102] Rosner presumed that Hamilton (notorious for sexual and financial scandalous improprieties) fabricated his trial "to impress his examiners and other readers . . . It is kinder to assume the medical faculty passed the thesis without reading it than to infer that they believed the trials had actually been carried out".[100]

WHAT HAPPENED AFTER LIND MOVED TO HASLAR?

In the first 2 of his 25 years at Haslar, Lind had 5743 admissions, of which one-fifth had scurvy. He presumably cured these patients with oranges and/or lemons or their juices, whose preparation and storage as an extract he discussed in a letter on the dangers of lead glazing to the *Scots Magazine* of May 18, 1754. He later described this *rob* in detail in his 1772 third edition of his *Treatise*.[103] As well as curing scurvy with oranges and lemons on the *Salisbury* and at Haslar, Lind advocated preventing scurvy with their juices on naval ships as the practice had long been so successful on merchant ships.

Lind modestly ended his advertisement to the 1772 third and last edition of his *Treatise*: "I shall not further enlarge; being persuaded I can carry my researches no further; without launching into a field of conjecture and uncertainty. Work indeed more perfect, and remedies more absolutely certain . . . yet more enlarged experience must ever evince the fallacy of all positive assertions in the healing arts".

Lind's total failure as advocate from his 1753 *Treatise* until his death in 1794 has been much discussed. The authoritative Oxford Dictionary of National Biography pointed out, "The *Treatise* notably does not end with a ringing declaration to the Admiralty that seamen must regularly be issued with orange or lemon juice. . . . The *Treatise* as a whole did not deliver a single, clear, weighty recommendation."[104] Lind's failure has been attributed variously to his unforceful personality of a humble unhonored unaristocratic Scot, who lacked influence on the rigid authoritarianism of the navy and its class-conscious political grandees. Lind had suffered like Smollett's *Roderick Random* "disdainfully 'cut' by Captain Oakham 'who was too much of a gentleman to know a

surgeon's mate even by sight.' " Surgeon Vice-Admiral Sir Sheldon Dudley emphasized that Lind was exceptionally unassuming and was never given public recognition in his own land such as the academic honors he was awarded in France and Denmark. Lind was so self-effacing that in 1791 he was a member of a naval board that awarded a £5000 prize to Surgeon Irving RN for a salt-water still that Lind had invented in 1761.[105] Nevertheless, his failure to persuade the navy to adopt his *rob* must have been primarily due to its unimpressive efficacy at sea, presumably because he had boiled this juice (see above).

WERE RIVAL TREATMENTS OF SCURVY EFFECTIVE?

Meiklejohn has reminded us that two other contemporary books on scurvy were more influential.[106] Anthony Addington (1713–1790) had been at Winchester and Trinity College, Oxford, and became a physician to prime ministers and the king. However, he had neither been to sea nor seen cases of scurvy so his 1753 *Essay*[107] had no clinical merit and Lind claimed he had tested Addington's sea-water cure and found it useless. Charles Bisset (1717–1791) was a contemporary of Lind at Edinburgh, had 5 years' experience in the navy, and proposed his own remedies for scurvy in his 1755 *Treatise*, dedicated to Lord Anson, lord high admiral of Great Britain.[108] Bisset accepted that in the treatment of patients fresh citrus juices were the most powerful antiscorbutics known, but he gave no evidence for the efficacy of his regimen to prevent scurvy – rice, gruel, sugar, wine, purging, sweating, and molasses.

However, Bisset did influence Sir John Pringle (1707–82), yet another Edinburgh physician, president of the Royal Society and the founder of modern military medicine, who was also keen on the health of seamen.[109] Pringle advised the admiralty against Lind's *rob* and to test instead *wort*, an infusion of malt that was proposed by David MacBride (1726–1778), who was born in Northern Ireland and had studied at Glasgow University.[110] MacBride's naval captain brother John was a friend of the First Lord of the Admiralty Lord Sandwich, who later promoted him to admiral.[111,112] MacBride's detailed claims for the efficacy of his malt on his brother's HMS *Jason* were, in retrospect, unconvincing, especially because the sailors were given oranges and apples as well as the *wort*.

On James Cook's first voyage of 1768–1771 on the *Endeavour* there were three outbreaks of scurvy,[113] and his scientist Sir Joseph Banks cured his own scurvy with a personal supply of lemon juice that he had been advised by the naval surgeon Nathaniel Hulme to bring from London.[114] Captain Cook was urged by the admiralty to study a range of antiscorbutics on his three voyages around the world on *Resolution* between 1768 and 1780.[115] He used "MacBride's Malt", "Sour Kraut", "Portable-Soup" and Lind's *rob* of lemons and oranges, and took every opportunity to add to the soup green vegetables, preferably fresh, or washed and stored between layers of salt.[116] Cook took excellent care of his men and there were only five episodes of scurvy (but no deaths) on *Resolution* between 1772 and 1775, almost certainly because of his continual encouragement of fresh fruit and vegetables – breadfruit, cabbage, celery, cranberries, onions, scurvy grass, spruce beer, sweet potatoes – all now known to be useful sources of ascorbic acid.[117] It is probable that the two vaunted antiscorbutics he was asked to test, Lind's *rob* and MacBride's Malt, had both been boiled and therefore lost much of their activity.[118] Nevertheless, in 1776 Captain Cook wrote to Pringle, "I entirely agree with you that the dearness of the Rob of lemons and oranges will hinder them from being furnished in large quantities, but I do not think this so necessary; for though they may assist other things, I have no great opinion of them alone".[119] The admiralty recommended MacBride's Malt rather than lemon juice as scurvy prophylaxis for the next 20 years.

From the 1760s, more and more writers referred to Lind's remedy and some tried to cost citrus fruit and its juices. The Spanish fleets had long known the efficacy of citrus fruits.[120] In 1767 French health physicians accepted Lind's lemon juice, but their naval administrators did not and their sailors continued to suffer from scurvy.[121–123] Even in 1818, a French ship bound from South America to Havre had one-third of its crew dead of scurvy, one-third dying, and the others more or less diseased.[124] The experienced sea surgeon William Northcote accepted that scurvy was due to lack of fresh vegetables and that ripe fruits were curative. He recommended to all navy and merchants' surgeons as particularly convenient a quintessence of oranges and lemons sold in Plymouth at 8 shillings per pint, with a teaspoon sufficient for a quart of punch.[125] He accepted that Lind's oranges and lemons were an infallible cure for scurvy and cited parliamentary data of December 1760 of naval morbidity and mortality (see below).[126] Yet there were still chemists such as Francis Spilsbury selling from his Spilsbury Dispensary his useless Spilsbury Drops that probably contained mercury and antimony.[127]

Evidence mounted for the efficacy of lemon juice, and individual admirals, such as Lord Howe in New York in 1776, used their own initiative to buy lemons for their sailors.[128] Meanwhile, outbreaks of land scurvy continued in armies, asylums, and hospitals. Yet, in Sweden in 1700, the army was spared the scurvy of civilians because the royal physician Urban Hjärne ordered every soldier a daily pint of ale steeped in fresh pine shoots.[129] When an outbreak of scurvy occurred in the Imperial Army in

Hungary, the College of Physicians at Vienna sent out a large supply of the most approved antiscorbutic herbs, but they were useless because the college had dried them. Scurvy was common at sieges. In Thorn in 1703, 5000 of the garrison died of scurvy, and at Alexandria in 1801, 3000 French were hospitalized.[130] The siege of Gibraltar in 1780 led to "dreadful ravages" of scurvy that were cured in a few days after the capture of a boatload of oranges and lemons from Malaga. The fresh juice was conveniently prepared by adding 5–10 gallons of brandy to 60 gallons of lemon juice, and administering 1 to 4 ounces daily.[131]

HOW DID THOMAS TROTTER IMPROVE ON LIND'S *ROB*?

An even more compelling argument than restoring sailors to health was for merchants to keep African slaves alive en route to the Americas. Thomas Trotter (1760–1832), a baker's son, became a surgeon's mate on the *Berwick* in 1779 in the Channel and the West Indies. In 1784, when he studied medicine at Edinburgh, and took his MD, the eminent Cullen was still skeptical regarding the causes and cures of scurvy. Trotter wrote his *Observations on the Scurvy* in 1786 and wisely dedicated it to Viscount Howe, first lord of the admiralty.[132]

In 1783 Trotter had been surgeon to the slave-ship *Brookes* from Liverpool, a city that had recently wrested that trade from Bristol. The first educational responsibility of the 1749 Liverpool Infirmary was to set up rigorous examination boards to certify slave-ship surgeons, and 151 of the 634 candidates between 1789 and 1807 failed. The surgeon of a slave ship had only a small salary but was given two slaves and these he could sell at the end of the transatlantic voyage. Trotter was convinced that Lind's lemons and limes and their juices could save "the lives of poor wretches who perished" and their owners "some thousand of pounds" a voyage, but the slavers balked at the cost of extra food. Trotter did not follow Lind in heating to evaporation the lemon juice; he merely strained it, covered it with a little olive oil, and after bottling, the juice was still effective on the coast of Africa 14 months later.

Not only did Trotter solve the problem of keeping lemon juice effective for months, he also performed another prospective controlled therapeutic trial of scurvy. He had noted that slaves threw away ripe guavas but devoured green ones. He therefore took nine slaves with scurvy kept under the half-deck, and personally gave one group limes three times a day, the second group green guavas, and the third group ripe guavas. After 1 week, the first and second groups were cured but those given ripe guavas were no better, making the point that vinous fermentation impairs the antiscorbutic factor, just as wine, beer, and rum were less effective for scurvy than fresh grapes, malt, and molasses.[133]

In 1789, Trotter rapidly and successfully cured 80 Irish transported convicts with oranges and lemons. He rejoined the navy in 1790 and in his second edition of 1792 (dedicated to the newly created Earl Howe) he deprecated the then-current naval use of MacBride's Malt and re-emphasized the virtues of lemon juice for both sailors and slaves.[134]

In 1793, Trotter became second physician at Haslar, which he reformed and then published on the running of that hospital. His dedicatee Lord Howe appointed him Physician of the Channel Fleet, after which Trotter wrote a three-volume *Medicina Nautica* (also dedicated to Earl Howe). By 1794, the Dutch and English East India Companies were routinely equipping their ships with lemon juice,[135] but the English were also buying lime juice from the Dutch Gold Coast.[136]

HOW DID GILBERT BLANE AND TROTTER PERSUADE THE ADMIRALTY?

Gilbert Blane (1749–1834), yet another Scot, had studied in Edinburgh and qualified as an MD in 1778 in Glasgow. Cullen recommended him to go to London to seek the patronage of the Scottish surgeon William Hunter.[137] Hunter arranged for Blane to be Lord Rodney's personal physician and to treat his gout. In 1779 Rodney took Blane with him to the West Indies. "Whereas both Trotter and Lind had gone through the mill as surgeon's mates before they got an opportunity to qualify as physicians to the fleet, Sir Gilbert Blane never suffered from the indignities of the cockpit and the lower deck. He joined the Navy as the pampered protégé of a great and influential admiral."[138]

Blane persuaded his admiral to instruct all ships surgeons to keep precise daily records of the numbers, diagnoses, and fates of sick sailors for Blane to tabulate. Blane was made physician to the West Indies fleet, and in about 1780 in Antigua he wrote and had privately printed *Memorials* for the admiralty, pointing out that almost one in seven (1577 of 12,109) of the sailors of this 20-ship squadron had died of disease, but only 59 had been killed by the enemy. This number of deaths "would man three of His Majesty's ships of the line".[139] Many deaths were from scurvy, and he (as had Trotter) recommended better food and use of antiscorbutics: "Scurvy . . . may be infallibly prevented, or cured, by vegetables or fruit, particularly oranges, lemons or limes." Blane's econometric argument to the admiralty was as follows: "Every fifty oranges or lemons might be considered as a hand to the fleet in as much as the health, and perhaps the life, of a man would thereby be saved." By 1782 this fleet's mortality was reduced to one in twenty. While in the navy, Blane

met the Duke of Clarence, became his physician, and then physician to the Prince Regent, later King George IV. Blane preserved lemon juice with a small amount of spirits, rather than Lind's heat, and he was also prepared to use 30 casks of limes taken in a prize in 1782.[140] In the second edition of his *Diseases of Seamen* he compiled a list of *Assortments of Medicines* to be carried to sea. For 100 men, for 1 year, he included "lemon juice clarified, and preserved by adding to it, a small proportion of ardent spirits, five gallons."[141]

Blane then left the navy and, with Lord Rodney's patronage, was elected in 1783 by 98 votes to 84 as Physician to St. Thomas' Hospital. There, his colleagues admitted he was "a painstaking physician . . . he was so cold in temperament, that we called him *Chilblaine*". Among his many rich private patients was the First Lord of the Admiralty George Earl Spencer who appointed Blane as naval commissioner for the sick and wounded. In 1793, Blane recommended his friend Rear Admiral Sir Alan Gardner, one of the lords of the admiralty, to supply the seamen of his squadron, sailing non-stop for 19 weeks to India, with lemon juice ¾ ounce daily; no scurvy developed on the *Suffolk* and, similarly, in ships of the Channel Fleet.[142,143] In January 1794, the Victualling Board refused Trotter's request for lemon juice for the fleet about to sail from Spithead, so that when scurvy struck this fleet Trotter got Admiral Waldegrave's permission to buy £70 of lemons and oranges, while Waldegrave purchased fruit from a Swedish vessel. Trotter estimated that 36 sound lemons made one gallon of lemon juice, and every ship was supplied with 30 gallons. In early 1795, Trotter sent memoranda first to the Victualling Board and then to Blane's Board, and by August the admiralty ordered lemon juice for the fleet at Portsmouth.[144]

DID NAVAL SCURVY DISAPPEAR AFTER 1795?

Thus, it took patronage for lemon juice to be made a regulation issue. At first, this juice was supplied to individual fleets, but in May 1796 the Sick and Hurt Commission agreed to supply all naval ships on foreign service with lemon juice, and in 1799 all ships on the British coast as well. Lemons became so scarce, and the consumption of the juice so great, that Trotter bought bushels of apples instead. Between 1795 and 1814 the admiralty issued 1.6 million gallons of lemon juice. Sweet lemons were imported, especially from the Mediterranean region. Nelson turned Sicily into a vast lemon juice factory.[145] Scurvy then more or less disappeared from ships of the navy. Any cases could be treated on board ship rather than needing admission to Haslar hospital, so that its wards no longer contained sailors with scurvy. Throughout this article there has been little or no reference to what sailors, as opposed to the admiralty, considered important in the management of scurvy. However, the issue of lemon juice was at first so delayed that one of the demands of the Nore mutineers in 1797 was for fresh supplies of vegetables and lemon juice.

Where Lind had failed, Trotter and Blane succeeded. They had nothing to add to causation, or the mode of action of lemon juice. "Lemon juice may be deemed a *medicine* . . . better as a *dietetic* modifying the alimentary matter. I am glad thus to escape from the slippery paths of theory, having no great confidence in the accuracy, nor the utility of such speculations."[146] Blane had a reputation in the navy of being unflappable, and his statistical analyses were unanswerable.

HAS THE MILITARY SIGNIFICANCE OF SCURVY BEEN EXAGGERATED?

In 1954, Rodgers, the naval historian, asserted that the military significance of scurvy has been exaggerated, and that "at the end of the Seven Years War [1756–63] scurvy was no longer a problem on British warships".[147] However, the published data of 1760 state that of 184,899 sailors, 1512 were killed in action and 133,708 were "lost" (discharged from hospital, unserviceable, or deserted[148,149]) and all reports agree that scurvy was the main cause of naval morbidity and mortality. In 1782, in the American War of Independence, the sick list was 23,000 out of 100,000 sailors – "One can almost argue that the American colonies were lost because of the incidence of scurvy."[150]

Of 175,990 sailors raised from 1774 to 1780, 18,545 died of disease (1 in 10), and 1243 were killed. Between 1779 and 1794 the naval sick rate improved from 1 in 2.45 to 1 in 4, and the death rate from 1 in 42 to 1 in 86. Between 1794 and 1813 the naval sick rate fell from 1 in 4 to 1 in 10.75 and the death rate from 1 in 86 to 1 in 143.[151] It was then possible for the British Navy to blockade French ports for years at a time, winning the Napoleonic War by sea power. "Of all the means which defeated Napoleon, lemon juice and the carronade gun were the two most important."[152] Naturally, British historians may be patriotically partial, but some French maritime historians also attributed the British victory to their well-trained sailors, hygiene, nutrition, and lemon juice.[153,154] Did Rodgers mention James Lind? Yes, but only that he "started his career with some useful observations on scurvy".

WAS LIME JUICE AS EFFECTIVE AS LEMON JUICE?

In the 19th century, steam power shortened all sea journeys so that few ships were away from ports and fresh foods for months at a time, with the one exception

of polar voyages. Because there was still no agreement on the best method of preserving lemon juice, the navy ordered a prospective controlled trial. HMS *Investigator* sailed to the Arctic in August 1850 in search of Sir John Franklin.[155] The lemon juice was either boiled with no spirit, or not boiled with 1 in 10 added brandy, each in a 64-ounce bottle, with a ½ inch of olive oil above, then corked and sealed. At that time, provisions and juice were issued to each sailors but there was "no guarantee whatever that each man drinks his own allowance". Addington therefore divided the men by tubs, and "each man drank his allowance in presence of an officer", just as Lind (or his staff) in 1747 and Trotter in 1783 had given the fruit to their subjects rather than trusting the sailors to take it themselves. The normal juice dose was one ounce daily, and no scurvy developed until the crew had to be placed on short rations and the lemon juice dose reduced to ½ ounce per day in September 1852. At the end of the voyage, in June 1853, the bottles with the boiled juice had sediment at their bottoms, but the brandy added juices were still clear; therefore, Addington recommended this method.

Thus, by the middle of the 19th century there was ample evidence that scurvy was totally preventable, and totally treatable, by lemon juice, indicating this article should simply have closed here. However, scurvy did suddenly return in the British Navy in 1875 and another 40 years were required to unravel the bizarre reasons for this anticlimax.

In 1875, the knighted Sir Alexander Addington, naval medical director general, gave specific instructions about adequate supplies of lemon juice for the sailors and sledge parties on the 1875–1876 Nares Arctic expedition. However, Addington was probably not aware that the lemon juice he ordered was supplied as lime juice. The expedition had to be abandoned because of severe scurvy leading in 1877 to both a parliamentary and an admiralty inquiry.[156,157] These inquiries noted that scurvy had developed in spite of the prophylactic lime juice issued to the sailors (and none to the sledge parties) and from that date the navy lost confidence in the efficacy of "lemon" (actually lime) juice in preventing scurvy. Thus, an *Army and Navy Gazette* editorial concluded in 1877 "there is no question of doubt that we have not in lime-juice the true preventative for scurvy".[158]

HOW WAS THE SCIENCE OF SCURVY AND ANTISCORBUTICS SOLVED?

In Oslo in 1907, Axel Holst and Theodor Frölich produced a valid animal model of scurvy by manipulating the diet of guinea pigs, and they demonstrated the antiscorbutic properties of apples, (unboiled) cabbage, lemon juice, and potatoes.[159] Their choice of the guinea pig was fortunate because we now know that although most animals can manufacture their own vitamin C in their body the exceptions are man, monkeys, and guinea pigs. In 1912, Casimir Funk at the Lister Institute, London, classified beriberi, scurvy, and rickets as three different deficiency diseases, lacking the organic bases that he named *vitamines*.[160] The biochemists then isolated the antiscorbutic substance that proved to be hexuronic acid, which was given the name "ascorbic acid" in 1928 by Albert Szent-Györgyi (Nobel laureate in 1938).[161]

In 1918, Dr. Harriette Chick and Ruth Skelton, also at the Lister Institute, showed that guinea pigs on a basic diet developed scurvy even when given preserved lime juice, that fresh lime juice had only a quarter of the potency of fresh lemon juice, and that animals who developed scurvy on lime juice were cured by fresh lemon juice.[162] Their tests showed that the British Army's and Royal and Merchant Navy's lime juices had little or no antiscorbutic properties, nor did four of six commercial samples, presumably from loss of activity in the storage and manufacture of the juice, especially destruction by copper tubing. They therefore reviewed the sources of the anti-scurvy juices used by the navy, but neither of the inquiries into the Nares expedition seemed aware of this change in antiscorbutic juices from 1860. The Lister bioassay estimate of lime juice having only one-quarter of the efficacy does not correspond to subsequent biochemical measurements, where lime juice had half or even two-thirds the concentration of ascorbic acid of lemon juice. This discrepancy could be due to the Chick-Skelton sample of "fresh" limes having travelled from Dominica, and might, during World War 1, have been 1 month old and therefore lost potency in bioassay.

The definitive and exhaustive study on the lemon versus lime juice controversy also came from the Lister Institute whose Alice Henderson Smith went through the admiralty archives.[163] Before 1796, the lemons came mostly from Spain, but when that country became a French ally, the lemons were imported from Portugal. In 1798, Nelson conquered Malta, and after 1803 lemons were imported thence (and from Sicily) for the British Navy worldwide. Nelson's surgeon bid for 30,000 gallons at 1 shilling (5p) per gallon (instead of 8 or 9 shillings [40–45p] for inferior juice in London), but had to settle for 20,000 gallons for 1/6d (7½p) per gallon, with 50,000 gallons to be delivered to England.[164] The quality of the lemons varied with the season in which they were harvested, the soil, the fertilizer, and the side of the tree on which the fruit grew.[165] There would also be variations in the juice manufactured by the contractors, so that the navy later prepared the juice at Deptford. Scurvy still

flourished in the Merchant Navy until an Act of 1844 made "lime or lemon juice" compulsory at ½ ounce per day.

In 1845, the Governor of Bermuda had suggested that the navy should switch to lime juice from the West Indies, and in 1846 the ships stationed there were supplied locally, even though the cost was higher. In 1852, Edmund Sturge of Birmingham bought land in Montserrat for huge lime plantations, so in 1860 the admiralty contract specified that the whole navy should be supplied with juice from limes from the West Indies (but from 1869 onwards bottled in Liverpool) instead of from lemons from Europe. The admiralty quality-control comparison of the two fruit juices was based then, and for the next half-century, on the only measurement available, namely acidity,[166] because there was then no measure of the antiscorbutic factor, either by chemistry or bioassay. The West Indies limes had higher acidity than Mediterranean lemons, another factor influencing the admiralty decision to replace lemon juice by lime juice.

British ships became nicknamed *limey-ships*, and British sailors and indeed Britons called *limeys*.[167] However, by 1863 an army surgeon complained that "few ships . . . pass through a voyage of more than four, or even three, consecutive months, without being visited by this pestilence . . . As to the generally supposed antiscorbutic properties of preserved milk, meats, vegetables, lime juice, such as we find in general use, and other specifics, I do not entertain the slightest belief."[168] The *Dreadnought* hospital in London immediately riposted, "Scurvy is most undoubtedly preventable. Lime-juice (good in quality and constant in quantity) . . . are given generally to all ships belonging to this port; and hence the immunity from scurvy that the crews generally enjoy . . . Glasgow, Liverpool and North country ship-owners are, by carelessness and superlative disregards of the wants of the sailors, perpetuating a disgrace that ought long ago to have been blotted out of Britain's shortcomings".[169]

Indeed, in the following year the *Times*' Liverpool correspondent stated that "A large quantity of so-called lemon-juice which is supplied to ships going on long voyages contain no juice of the lemon; it is manufactured in this country from tartaric and other acids, at a cheap cost, and flavored with essence of lemon to imitate the genuine article. I have had many samples analyzed, and found them to be made up."[170] The *Lancet* was therefore not surprised that in the previous year there had been 86 cases of scurvy admitted to the *Dreadnought* and of "men admitted to the *Sailors Home* at Poplar, about half are at the time of their admission suffering more or less from scurvy, and of these perhaps a twentieth part are seriously damaged". The statutory ½-ounce dose was doubled by the Act of 1867, after which time admissions decreased at the Seamen's Hospital London.

WHAT WERE THE OTHER THEORIES FOR THE CAUSES AND TREATMENTS OF SCURVY?

Oblivious of the abolition of scurvy in British ships by lemon juice while it flourished in the lemonless American, Austrian, French, and German boats,[171] together with the failure to understand the mechanism of the failure of lime juice to prevent or cure scurvy, many scientists refused to accept that scurvy was a deficiency disease.[172] Advances in clinical chemistry in the early 19th century made it possible for clinicians to measure specific substances in food and in patients with scurvy. In 1848, Alfred Garrod (father of the more famous Archibald) found potassium to be low in scorbutic diets and in the blood and urine of patients with scurvy, who rapidly responded when given potassium salts, or milk and fresh vegetables.[173] Garrod's paper was remarkably influential as the first biochemical study of scurvy. Thus, in the years of the Civil War in the United States, it was held to be "very generally accepted by the profession" and was one factor in citrus fruits not being given routinely to the soldiers for prophylaxis and/or treatment of scurvy.[174]

In 1877, Ralfe confirmed this low urinary potassium (and free acidity) in scurvy. However, he emphasized that hypokaliuria could not be the cause of scurvy because strong high-potassium beef-tea corrected the low potassium, but not the scurvy, whereas scurvy is cured by lime juice.[175] After the Nares Inquiry, one naval surgeon suggested that "it is the protein compounds that are the true antiscorbutics".[176]

In 1897, the Norwegian polar explorer Fridtjof Nansen cited Dr. Torup, professor of physiology at Oslo, as proposing that scurvy was a form of ptomaine poisoning (an Italian term of 1870) from badly preserved meat and fish,[177] and a subsequent *Lancet* editorial called scurvy "a condition of acid intoxication".[178] By 1900, this ptomaine theory was tested in monkeys who developed diarrhea and spongy gums on tainted, but not on fresh, meat.[179] However, the chief advocate of the acid intoxication hypothesis was the distinguished immunologist Almroth Wright, professor of pathology at the Army Medical School, Netley from 1892.[180,181] Wright blamed scurvy on eating acid meat and cereals, rather than alkaline green vegetables, tubers, and fruit. He described seven patients with such acidity that were treated with salts of organic acids such as sodium lactate or bicarbonate with improvement in their acidity, but four died, and perhaps only patient no. 1 had a history typical of scurvy. Wright persisted with his acid intoxication model and its corollary, the treatment with alkalies,[182,183] so that the 1911 *Encyclopaedia Britannica* favored this suspect unknown microorganism of "the more chemical school of pathologists".[184] All these models were abandoned with the isolation of ascorbic acid as vitamin C (see above).

WHY DID ANTARCTIC EXPEDITIONS SUFFER FROM SCURVY?

At the beginning of the 20th century, there were several South Pole expeditions, all of which took precautions against scurvy but almost all of which suffered from it. All the men on Gerlache's 1898–1899 *Belgica* expedition developed scurvy and they were saved only by eating fresh meat of penguins and seals. Robert Scott's 1901–1903 *Discovery* expedition relied on Almroth Wright's bad meat/ptomaine theory and his pooh-poohing of lemon juice. Scurvy appeared and was controlled when Dr. Reginald Koettlitz ordered daily fresh seal meat. Ernest Shackleton had scurvy and was invalided home. He returned in the 1907–1909 *Nimrod* expedition, when scurvy was mostly avoided by eating the ponies, but there were several severe cases and the chaplain died.

Captain Scott on his last and fatal 1911–1912 expedition still held to the fashionable acid-intoxication model taught by Wright (by then knighted and professor at St Mary's Medical School) as did one of his doctors (Atkinson) although the other (Wilson) regarded this theory as not proven. Scott and three companions reached the South Pole on 18 January 1912 only to find that Amundsen's group had arrived there on 14 December 1911. Amundsen's team came back safely but Scott's polar party all died on their return journey. The cause of their deaths has been disputed for the last hundred years. The majority medical viewpoint has been that Scott's party died from lack of calories and vitamins (especially C) in the severe cold.[185–187] Some biographers agreed[188–191] while revisionists blamed only the extreme cold.[192–194] Carpenter was "left with an open mind on this point".[195]

Shackleton's 1916–1917 Imperial Trans-Atlantic Expedition was advised by Colonel Beveridge of the Royal Army Medical College to use lime juice. The ship's surgeon, Eric Marshall, had been on the 1908 expedition and used successfully bottled fruit, vegetables, and fresh seal meat. The 1916 biologist and "surgeon" was a Cambridge medical student John Lachlan Cope who was up-to-date in his advice: "Scurvy is not due to any germ or bacteria and cannot be cured or prevented by tinned or dried food. There is in the blood of man . . . a substance known as a vitamin." Most of the expedition remained free of scurvy but a group became marooned, developed scurvy, and one of them died.[196]

DID SCURVY REAPPEAR IN THE WORLD WARS?

In peacetime, merchant ships were never far from ports and fresh foods but in both wars German auxiliary cruisers might be at sea for months at a time. In World War I there were outbreaks of beriberi (see above), but scurvy was rare, presumably because it was standard German naval practice to give prophylactic lemon juice. In World War II the prophylactic was ascorbic acid in 50 mg tablets, but in one ship at sea for 602 days the daily dose had to be doubled or trebled because of deterioration of these tablets with time.[197] Thus, sailors' scurvy has effectively been abolished, and civilian patients with scurvy are generally on unusual diets.

AFTERWORD: WAS THE ADMIRALTY TO BLAME FOR THE 42-YEAR LAG?

In 2005, Tröhler re-examined the 40-year lag between Lind's "proven" treatment and its actual introduction. He rejected the common allegation that this was "one of the most foolish episodes in the whole history of medical science and practice".[198] Although Lind had claimed to prove the efficacy of citrus fruits in curing scurvy, his failure to produce an effective storable preserved citrus juice meant the admiralty had no recommendable proven preventative antiscorbutic until the 1790s. The admiralty can be blamed for the return of scurvy after it substituted lime juice for lemon juice in the 1850s, but this decision was not miserly; it was colonial preference. Fortunately, subsequent science did isolate and synthesize ascorbic acid and the history of scurvy could finally close.

CONCLUSION

For centuries, many sailors, some ships' doctors, but few university-trained physicians cured and prevented scurvy with oranges and lemons. James Lind in 1753 described his prospective controlled therapeutic trial of 1747, but I do not consider his report entirely reliable. Nevertheless, Lind's books stimulated Thomas Trotter and Gilbert Blane to persuade the British Navy in 1793 to abolish scurvy by compulsory lemon juice, only for it to reappear after 1860, especially in polar regions, when lime juice was substituted. In the last hundred years scurvy was shown to be a deficiency of an essential food factor, and this vitamin C was characterized as ascorbic acid that could at last both prevent and cure scurvy.

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