

**An analysis of The United States and United Kingdom smallpox epidemics (1901 to 1905)
– the special relationship that tested public health strategies for disease control**

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Abstract: At the end of the nineteenth century the northern port of Liverpool had become the second largest in the United Kingdom. Fast transatlantic steamers to Boston and other American ports exploited this route, increasing the risk of maritime disease epidemics. The 1901-1903 epidemic in Liverpool was the last serious smallpox outbreak in Liverpool and was probably seeded from these maritime contacts, which introduced a milder form of the disease that was more difficult to trace because of its long incubation period and occurrence of undiagnosed cases. The characteristics of these epidemics in Boston and Liverpool are described and compared with outbreaks in New York, Glasgow and London between 1900 and 1903. Public health control strategies, notably medical inspection, quarantine and vaccination differed between the two countries and in both settings, were inconsistently applied, often for commercial reasons or public unpopularity. As a result, smaller smallpox epidemics spread out from Liverpool until 1905. This paper analyses factors that contributed to this last serious epidemic using the historical epidemiological data available at that time. Though imperfect, these early public health strategies paved the way for better prevention of imported maritime diseases.

Key words: smallpox, maritime, epidemic, public health, Boston, Liverpool.

Introduction

A constellation of factors contributed to the pattern of smallpox outbreaks in the United States and United Kingdom at the onset of the twentieth century. This dreadful disease had occurred in sequential epidemics throughout the nineteenth century in British cities ¹, and was largely imported from Europe.² In contrast in the United States, with the exception of mild smallpox in the southern States and a few severe cases in the city of New York, the disease had, by 1897, entirely disappeared from the country.³ This changed in late 1896, following an outbreak of a very mild type of smallpox which originated in the southern States and spread over four years to north-eastern cities and ports. Historical epidemiology suggests importation of smallpox from these ports to the United Kingdom, and particularly to Liverpool from Boston in 1901. The barrier of the Atlantic Ocean was now bridged by fast transatlantic steamers, shortening crossing times to less than six days⁴, heightening commercial shipping interests while allowing rapid dissemination from infected sailors. The Liverpool Dock System between 1890 and 1906 was radically reconstructed allowing intake of a greater number of larger ships from America.⁵ The city expanded to become the second largest port in the United Kingdom at the turn of the century.

This paper describes the factors that contributed to the pattern of national smallpox outbreaks in the United States and United Kingdom and specifically in the cities of New York, Boston and Liverpool between 1901 and 1903. Re-constructing these historical epidemics using imperfect sources is challenging and methodological limitations are considered. The primary aim is to describe public health approaches to control smallpox during epidemics in major transit ports for Atlantic shipping and factors which influenced these efforts. Experience with different responses helped develop a more evidence-based approach to disease control and to anticipate the general public's response to such measures. A knowledge base for disease control was growing, given experience with other maritime imported epidemic diseases such as cholera and plague, but smallpox differed due to the availability of an effective preventive vaccine, the efficacy of which had not been fully assessed. In analysing these data, a secondary aim is to examine the evidence that smallpox cases occurring in Liverpool in 1901 and 1902 may have originated from American imported cases. Peak smallpox incidence in the United States spanned the period 1901 and 1902 and a high infection risk was channelled via ships travelling from Boston to Liverpool, where the outbreak peaked in April

1. Charles Creighton. *A History of Epidemics in Britain, Volume Two 1666-1893* (Frank Cass and Co. Ltd., London, 1965, First edition 1894), 582-601 and 604-619.
2. Donald R. Hopkins. *Princes and Peasants, Smallpox in History* (University of Chicago Press, Chicago, 1983), 87 -96.
3. Charles Value Chapin. Variation in type of infectious disease as shown by the history of smallpox in the United States 1895 – 1912. *Journal of Infectious Diseases*, 13, (1913), 171-196.
4. P. J. Hugill. *World Trade since 1431* (Baltimore, Johns Hopkins University Press, 1993) 128.
5. William Farrer and J. Brownbill (eds), in *A History of the County of Lancaster, Volume 4*, (London, 1911, British History Online <http://www.british-history.ac.uk/vch/lancs>), 41-43.

1903. Outbreaks across northern and central England were temporally related to the Liverpool epidemic.

The response to the epidemics was influenced by new epidemiological approaches and public health practices in both countries, although public health recommendations differed. In the United States, National and State vaccination strategies varied, as well as exemption regulations for children and adults. In both countries, commercial interests, variable clinical disease patterns, delayed diagnosis, and quarantine practices were influenced by local factors. An improved understanding of smallpox disease epidemiology slowly emerged and contributed to eventual control and elimination through broadened international efforts.

1. Methodological approaches to re-constructing historical epidemiological evidence

Extracting and interpreting late nineteenth century information from historical medical records on smallpox in order to quantify risk factors, a standard method in modern disease epidemiology, is subject to several pitfalls. Instead of meticulous tracing and recording of known cases and their contacts, the basic assumption at that time attributed the social and domestic habits of the poor to be the principal factors spreading smallpox.⁶ Emphasis on environmental and aggregate models of health and disease suggested that micro-organisms causing a specific disease were subordinate to the person's total environment.⁷ It is true that environmental conditions are important, but by the late nineteenth century it was also realised that epidemics were caused by a specific agent. Although the organism responsible for smallpox had not been isolated, it caused a recognised disease, which evoked introduction of tighter measures to prevent its importation. This included inspecting ships, monitoring smallpox outbreaks at home and abroad and some level of contact tracing.⁸ Europe-wide pandemics from 1870 to 1875 had led to improved vaccination strategies with legal provisions for enforcement. These developments, the basis of modern preventive epidemiology, occurred despite inadequate understanding of the causal agent, its modes of transmission, or the relative impact of behavioural changes and social determinants.⁹

Despite such progress, the present re-construction of historical outbreaks and examination of their risk factors is affected by several criteria which are difficult to quantify. These included: variable definitions of reported events; misdiagnoses; lack of detailed household transmission data; spatial heterogeneities; inadequate information on vaccine effectiveness - partly because of

6. Anne Hardy. *The Epidemic Streets. Infectious Disease and the Rise of Preventive Medicine 1856-1900* (Clarendon Press, Oxford, 1993), 134 and 145.

7. Charles E Rosenberg. *Explaining epidemics and other studies in the history of medicine* (Cambridge University Press, 1992), 299-301.

8. Alexander Mercer. *Infections, Chronic Disease, and the Epidemiological Transition: A New Perspective* (Rochester, NY, University of Rochester Press, 2014), 69.

9. Del Valle S, Hethcote H, Hyman JM, Castillo-Chavez C. Effects of behavioural changes in a smallpox attack model. *Mathematical Biosciences*.195, (2005), (2):228-51.

lack of reliable estimation methods; difficulties in early recognition of smallpox cases and confusion with chicken pox or measles; notification delayed until the afflicted person had been suffering for many days and the absence of explicit statistical analyses.^{10, 11} Since the length of the incubation period can only be known for individuals exposed early, late reporting compromised quarantine regulations which specified a period of 14 to 16 days. In practice it was based on clinical experience and limited epidemiological data. Similarly, vaccine coverage of the general, or sub-groups of the population was critical, in order to reach a target capable of interrupting an epidemic. In the modern era estimates of critical vaccine coverage are obtained by estimating the ‘reproduction number’ which is based on the average number of secondary cases which arise from a single index case in a susceptible population in the absence of interventions. During the early twentieth century lack of reliable statistical methods precluded measurement of vaccine effectiveness and, as a consequence, use of smallpox vaccine remained controversial. In this paper, vaccine efficacy is calculated from the data available, both in the United States and the United Kingdom. The Boston Health Department physician, Dr Frank Morse, pointed out in 1903 that accurate smallpox records had been kept only since 1888, and were reported in the Annual Reports of the City Health Department Surgeon, as well as the Annual Reports of the Surgeon General of the Public Health, and Marine-Hospital Service of the United States. Nevertheless this information provided no data on how many people were vaccinated or re-vaccinated out of the total population.¹² In the United Kingdom case numbers and locations were listed in the Annual Reports of City Medical Officers of Health, and the Metropolitan Asylums Board, and these provided crude estimates of vaccinated and allegedly vaccinated individuals, although criteria for identifying vaccine scars were unclear. Part of the analysis in this paper uses information based on these reports for the years 1901 to 1905. Monthly case notifications are available in both the United States and United Kingdom, but seasonal analysis of case fatality is limited as available reports provide mostly annual data on deaths. The availability of these data also enables the hypothesis to be evaluated that the Liverpool outbreaks originated in the United States where disease control measures differed and may have been less efficient.

2. Maritime relationships between Britain and the United States

Early twentieth century maritime quarantine regulations at British and United States seaports

In the late nineteenth century quarantine stations and regulations for the sanitary inspection of ships were present at many British seaports and general sanitary arrangements were satisfactory

10. Hiroshi Nishiura, Stefan O. Brockmann, Martin Eichner. Extracting key information from historical data to quantify the transmission dynamics of smallpox. *Theoretical Biology and Medical Modelling*, 5, (2008), 20. doi: 10.1186/1742-4682-5-20.

11. Karen Wallach. *The Antivaccine Heresy: Jacobson v. Massachusetts and the Troubled History of Compulsory Vaccination in the United States*. Rochester Studies in Medical history, (Boydell and Brewer, University of Rochester Press, 2015), 70-73, 253. Provides an extensive list of references covering the period 1900 to 1902 on difficulties of smallpox diagnosis in the United States.

12. *Ibid.*, 16.

in two-thirds of the sixty port sanitary districts.¹³ Similar arrangements were present on the Atlantic seaboard of the United States.¹⁴ Several diseases were cause for concern, including cholera, plague, yellow fever and smallpox.¹⁵ Sanitary inspection of all vessels entering British or United States ports was the main strategy available. The UK Public Health (Shipping) Act of 1885 extended the ordinary powers of local authorities granted in the 1872 Public Health Act to the Port Sanitary Authorities in respect of infectious disease.¹⁶ These initiatives allowed efficient intervention when vessels with infected crew or passengers entered ports.¹⁷ To this end, smallpox figures for countries from which other ships originated were included in reports in both countries,^{18, 19} and could be used to enhance surveillance.

There was some collaboration between the two countries. The United States Assistant Surgeon, Dr Carroll Fox (b.1874) stayed in the Liverpool United States Consulate for three months in 1902 to review infection control policy and practice and the numbers of smallpox and typhus cases.²⁰ He reported on six Liverpool municipal hospitals as well as on containment, refuse disposal and disinfection procedures, noting that steam disinfectors used in Liverpool were newer than those used by the Public Health Service at the quarantine station in Port Townsend, Washington. This exchange signalled some of the first international efforts to harmonise infection control practice across major sea routes for maritime transport. Yet, in September 1902, as Dr Fox completed his mission, eleven ships with infected seamen from Boston had already arrived, although Dr Fox failed to mention the Boston epidemic in his report.

In the last decade of the nineteenth century the twin systems of medical inspection and quarantine were in use, but with greater emphasis on medical inspection and case isolation. The risk posed by foreigners had become more evident to the general public in the United States as migration

13. Anne Hardy. Smallpox in London: factors in the decline of the disease in the nineteenth century. *Medical History*, 27, (1983), 128.
14. Howard Markel. A gate to the City: The Baltimore Quarantine Station, 1918-28, *Public Health Reports*, 110, 2 (1995), 218-219.
15. D. S. Barnes. Cargo, 'Infection,' and the logic of quarantine in the nineteenth century, *Bulletin of the History of Medicine*, 88, (2014), 75-101.
16. Public Health (Shipping) Act (1885), 48 & 49, and Public Health Act (1872), 75 & 76 Vict. c. 79, sec. 3, 20.
17. J. C .Burne. The Long Reach Hospital Ships and Miss Willis. *Proceedings of the Royal Society of Medicine*, 66, (1973), 1017-1021.
18. *Annual Report of the Surgeon General of the Public Health and Marine-Hospital Service of the United States, Fiscal year 1902* (Washington, Government Printing Office, 1903), 303-3.
19. *Annual Report of the Surgeon General of the Public Health and Marine-Hospital Service of the United States, Fiscal year 1904* (Washington, Government Printing Office, 1905), 100.
20. *Annual Report of the Surgeon General of the Public Health and Marine-Hospital Service of the United States, Fiscal year 1903* (Washington, Government Printing Office, 1904), 192-193. He later won recognition for the identification of a quirk in the flea population of San Francisco, California, and helped prevent a wider outbreak of plague which had been infecting the city population since 1900. *Public Health Reports*, September 25, 1908, quoted in David K.Randall. *Black Death at the Golden Gate. The race to save America from the bubonic plague.* (W.W.Norton and Company NewYork 2019), 210-211.

sensitised opinions, and foreigners became a focus for quarantine policies.^{21, 22} In the United Kingdom the Merchant Shipping Act of 1894 required medical inspection of all outward bound steerage passengers and crew, when services of a medical practitioner could be obtained, on board ship or preferably before embarkation.²³ In the Port of London, Gravesend, the Medical Officer for the Board of Trade commonly examined all persons as they proceeded along the gangway and refused them permission to proceed, if considered ill.²⁴ This screening had low sensitivity, but should have identified obviously sick travellers with facial rashes which might be a sign of active infection. As an alternative to inspection, the argument for quarantine of ships was contentious. A *Lancet* editorial commented in 1880 that it only survived because it was plausible, seductive, and fitted the unreasonable demands of certain continental powers, and that ‘it was derogatory to England that she should submit to these hideously farcical detrimental proceedings’.²⁵ Quarantine avoided the trouble of disinfecting and removing the sick, but was costly for trading sea ports. Moreover unless cholera, plague, or yellow fever was existent on board a vessel there was no legal authority for detaining her on sanitary grounds. Some had advocated the inclusion of smallpox in the cholera, plague, and yellow fever order; but a smallpox reservoir in the United Kingdom was assumed so its inclusion was considered inadvisable as it would deter international trade.

Quarantine stations

In Britain quarantine stations, including some more isolated off-shore establishments, had existed in the early nineteenth century. This remained the only effective measure until later in the century when contact tracing and surveillance were introduced. Port Sanitary Authorities established hospital ships in a number of locations around Britain to isolate suspected smallpox cases. In 1884 the Metropolitan Asylums Board moored three converted ships in the Thames to serve as a floating hospital,²⁶ primarily for indigenous cases arising during the 1884 -1885 London smallpox epidemic.²⁷ By 1899 the Infectious Diseases Notification Act required compulsory notification of infections, by which time, smallpox was the focus of attention.²⁸ In Liverpool in 1874 the Local Government Board, under the Public Health Act, permanently constituted the Liverpool Council with powers to inspect vessels on arrival and to appoint a quarantine station in the river Mersey where vessels could anchor. A quarantine station already existed at Hoyle Lake, an offshore area enclosed by sandbanks on the outer Mersey estuary, which provided accommodation for infected patients,

21. Barnes, *op.cit.* (note 15).

22. Alan M. Kraut. *Silent Travelers: germs, genes, and the "immigrant menace"*. (Baltimore, Johns Hopkins University Press, 1995), 50-77.

23. Port of London Sanitary Committee. Annual Report of the Medical Officer of Health to 31 December 1902. May 1903, 23 -25.

24. *Ibid.*, Appendix H, 77-91.

25. *The Lancet*, editorial, 1, (1880), 687-689.

26. Burne, *op.cit.* (note 17).

27. *London Metropolitan Asylums Board Annual Report 1900* (M. Corquadales and Co. Ltd., London 1901).

28. Infectious Diseases Notification Act (1899), 62 & 63 Vict. c. 8.

particularly cholera cases.²⁹ As the estuary was silting up and Liverpool port expanded, a land-based Port Sanitary isolation hospital was built in 1875 at New Ferry, isolated from the public, and with ship access via a long wooden jetty.³⁰

Procedures were in place for ship fumigation, cleaning and painting of vessels, disinfection of clothing, and vaccination of passengers and seamen, although often seamen refused vaccination.^{31, 32} This task was immense, given the number of ships passing through the Port of Liverpool. Over 1,200 cases of tropical diseases were admitted to the Port Sanitary Hospital in the period 1875 - 1963, including cholera, leprosy and smallpox. Some infectious diseases were still treated as ordinary patients in other Liverpool hospitals, including smallpox cases, which were later transferred to New Ferry.³³ As early as 1891 New Ferry was declared unnecessary. Instead, long haul ships proceeded directly to the Pier Head entrance of each Liverpool dock to answer questions on quarantine, a concession much appreciated by ship owners.³⁴ In 1896 quarantine was discontinued and officially replaced by medical inspection,³⁵ although in practice quarantine remained, but at the discretion of the Local Government Board, rather than a national policy.³⁶ New Ferry simply acted as an isolation hospital for eighty-eight years and was officially burned down in 1963. A commemorative plaque records its historic role and location and is the last physical reminder of a Port Sanitary hospital in the United Kingdom (Figure 1). Even today, quarantine is exerted only in exceptional circumstances.

[Place figure 1 near to here]

In the United States maritime quarantine was initially a State activity but was transferred to a national Public Health Service between the 1880s and the 1920s. The Marine Hospital, dedicated to the care of ill and disabled seamen in the United States Merchant Marines, the US Coast Guard and other federal beneficiaries, eventually evolved into the Public Health Service Commissioned

29. Thomas Herbert Bickerton. *Medical History of Liverpool from the Earliest Days to the Year 1920* (London: John Murray, 1936), 188.

30. Port Sanitary Hospital, New Ferry, City of Liverpool Smallpox Register, Wirral Archives, Cheshire Lines Building Centre, Birkenhead, Wirral.

31. Hardy, *op.cit.* (note 13), 122-123,129.

32. William Hanna. *Report on Marine Hygiene. Being suggestions for improvements in the sanitary arrangements and appliances on shipboard.* Liverpool Port Sanitary Authority (C. Tinling and Co. Ltd., 1917).

33. Liverpool and Emigration in the nineteenth and twentieth centuries. National Museums Liverpool, Maritime Archives and Library, Information Sheet 64.

34. John Booker. *Maritime Quarantine. The British Expansion, 1650-1900* (Ashgate Publishing Ltd., Hampshire, England, 2007), 547.

35. The Public Health Act 1896 (Statute 59 and 60, c19) made provisions with respect to epidemic, endemic and infectious diseases and repealed the 1825 Quarantine Act (Statute 6 Geo iv, c78), and sections in other acts in which quarantine was mentioned. The Act united for the first time the sanitary arrangements of the United Kingdom.

36. Booker, *op cit.* (note 34), 549-550.

Corps.³⁷ Quarantine stations were established³⁸, and a prescribed protocol followed, based on the vessel's sanitary history and presence of infected or deceased crew or passengers. Disease detection led to active disinfection and fumigation of ships and isolation of passengers. When a case of smallpox was detected, crew and passengers were expected to spend 14 days in quarantine when a case of smallpox was diagnosed on board, although breaches of recommended policies were often made, especially for travellers in first and second class.³⁹

3. Factors leading up to the Boston 1901-1902 smallpox epidemic in the United States

Smallpox, when recognised, was reported and case fatalities were recorded across the country. Dr Charles Value Chapin (1856-1941), an American pioneer in public health research and practice, and Health Superintendent (1884-1932) for Providence, Rhode Island, compiled a detailed outline of smallpox in the United States between 1895 and 1912.⁴⁰ By 1897, with the exception of mild smallpox in the south and a few severe cases in New York City, the disease had disappeared from the country. During 1896 cases of mild disease in Florida began to spread and within a period of about four years cases were detected all over the country.⁴¹ The rate of dispersion was exponential as the infection was mild, which meant patients remained active in their community and cases were under-reported.⁴² By 1900 this wave of infection reached north-eastern cities and by 1901 had carried smallpox to every state and territory in the Union. There had been an epidemic in New York City in late 1899, preceding that in Boston in 1901.^{43, 44} The main culprit was the milder strain (*Variola minor*), which had a death rate of two to six per cent among unvaccinated individuals, which was considerably lower than with the *Variola Major* strain.⁴⁵ *Variola major* nonetheless remained present in several American cities, particularly in the North-East.

Disease notification was incomplete in some cities and rural areas and some states omitted returns.⁴⁶ Using National Population Census data of 1900, and the Annual Report of state smallpox notifications of the Surgeon General of the Public Health and Marine-Hospital Service for

37. *United States Public Health and Marine Hospital Service Annual Report*, 1905, 221.

38. Markel, *op.cit.* (note 14).

39. Michael Willrich. *Pox. An American History* (The Penguin Press, New York, 2011), 219.

40. Chapin, *op.cit.* (note 3), 186.

41. Hopkins, *op.cit.* (note 2), 288.

42. Gareth Williams. *Angel of Death. The Story of Smallpox* (Palgrave, Macmillan, Hampshire, 2010), 331-332.

43. Chapin, *op.cit.* (note 3), 186.

44. Willrich, *op.cit.* (note 39), 41-74, 167.

45. *Thirty-First Annual Report of the Health Department of the City of Boston for the Year 1902* (City of Boston Printing Department, 1903), 36.

46. *Ibid.*, 172.

1901^{47, 48} incidence for individual states returning notifications can be estimated. Figure 2 shows these estimates by state between 28 June 1901 and 27 July 1902 per 100,000 population. By 1901, as the epidemic spread north, incidence rapidly declined in southern states, ranging from less than one per 10⁵ population in Texas, to above 300 cases per 10⁵ population in North Dakota, Minnesota and Wisconsin. Annual smallpox notifications peaked nationally in 1901 at 56,857 cases (Figure 2). In Massachusetts, where the 1901 Boston epidemic occurred, annual incidence for that year was sixty per 10⁵ population. In New York City, between 1901 and 1902, 3,480 smallpox cases were reported with 720 deaths (incidence approximately 100 cases per 100,000 population).⁴⁹

[Place figure 2 near to here]

The Boston epidemic commenced in May 1901 in a large factory.⁵⁰ Cases were initially mild but by May 1901 severe cases began to appear. Their source was not known. The Health Department thought a letter received by a family from infected relatives living through the New York epidemic, was the cause.⁵¹ In the outbreak, twelve cases within forty-eight hours were admitted to hospital, and despite control measures, cases increased to thirty in September, forty-nine in October, 195 in November, and 201 in December 1901.⁵² By the end of October 1902 new cases of smallpox had appeared in nearly every section of the city with the epidemic continuing to 1903. In total there were 1596 cases (period incidence 284 per 100,000 population) with 270 deaths (17 per cent).^{43, 53} A smaller concurrent smallpox epidemic occurred in the adjoining city of Cambridge, Boston's close neighbour across the Charles river.⁵⁴ The nationally prominent senior public health officer in Boston, and Health Department Chairman, Dr Samuel Holmes Durgin (1839-1931), initially played down the epidemic, referring to it as only 'a flurry of cases' and a minor storm that would pass.⁵⁵ Durgin advised that schools should remain open and insisted that immediate vaccination rather than quarantine was the most effective control strategy. Many leading physicians in Boston preferred vaccination to sanitation and quarantine, and were somewhat indifferent to public anxiety over contagion.⁵⁶ Durgin was blamed for the continued spread of smallpox, not least because he had

47. United States National Census 1900. 12th Census population. United States Federal Census Records, Census records.com.

48. *Annual Report of the Surgeon General of the Public Health and Marine-Hospital Service of the United States, Fiscal year 1901* (Washington, Government Printing Office, 1902), 319-344, 579-582.

49. John Christie McVail. *Half a century of smallpox and vaccination*. Milroy Lectures, (Edinburgh: Edinburgh, E. & S. Livingstone, 1919), 10.

50. *Thirtieth Annual Report of the Health Department of the City of Boston for the Year 1901* (Boston, City of Boston Printing Department, 1902), 43.

51. Chapin, *op.cit.* (note 3), 186.

52. *Thirtieth Boston Annual Health Department Report, op.cit.* (note 50), 44.

53. Michael Albert, Kristen Ostheimer, Joel Breman. The last smallpox epidemic in Boston and the vaccination controversy, 1901 -1903. *New England Journal of Medicine*, 344, 5 (2001), 375 -378.

54. Wallach, *op.cit.* (note 11), chapter three, *The 1901-2 smallpox epidemic in Boston and Cambridge*, 75-78

55. *Ibid.*, 59.

56. *Ibid.*, 68-69.

allowed the Health Department physicians who treated smallpox patients to mingle and expose the public without taking precautions.⁵⁷ The cost of quarantine weighed heavily on officials and the controversy received front page press coverage.⁵⁸

The difference in severity of cases between epidemics warrants further examination. Characteristics of this epidemic can be gleaned from the clinical records of 243 patients consecutively admitted to the Southampton Street smallpox hospital in Boston.⁵⁹ Some hospital cases were caused by the *Variola major* form of smallpox, but these were not necessarily representative as many attacks were mild.⁶⁰ Smallpox has an incubation period of approximately seven to seventeen days, clinical onset leading to headache and backache, fever and malaise during a three day pre-eruptive period before appearance of a skin rash. Hospital cases presented with varying severity, but forty-seven per cent were the milder form of the disease, and most occurred in previously vaccinated persons. Full recovery took weeks with most deaths occurring as a result of unrecognised cases of smallpox in the city and suburban districts going about from place to place, with many unvaccinated people being exposed to infection.⁶¹ In the initial febrile phase (two to four days) individuals would be infective, but infected seafarers, or their contacts, may not have developed symptoms until nearly three weeks later. Individuals incubating the disease could readily depart on transatlantic ships and act as disease vectors.⁶²

The Boston epidemic coincided with a smaller smallpox epidemic (after accounting for the difference in population size) in London, commencing in June 1901 and lasting until January 1903, with 9484 notified cases.⁶³ There is no evidence that the London and Boston outbreaks were connected, despite their similar timing of onset. The daily surveillance returns to the Metropolitan Health Board for the 1901-1903 London epidemic indicated upwards of twenty different centres of infection. The origin of the disease for the first two patients could not be traced and, so far as was known, no cases arose from contact with them. Two foci at the end of June identified a Parisian male who infected four people, including a laundry worker who infected nine other contacts.⁶⁴ In August several other cases, whose contact source could be traced, seemed unconnected. Preceding both these epidemics was an outbreak in Glasgow, which began in April 1900 and lasted until July 1901

57. *Ibid.*, 152-153.

58. Cambridge Chronicle, *Three strong letters against quarantine, The Board of Health's opinion. Dr Brough's opinion*, July 19, 1.

59. Michael R. Albert, Kristen G. Ostheimer, David J. Liewehr, Seth M. Steinberg, Joel G. Breman. Smallpox manifestations during the Boston epidemic of 1901-1903. *Annals of Internal Medicine*, 137, 12 (2002), 993-1000.

60. Wallach, *op.cit.* (note 11), 69.

61. *Thirty-first Boston Annual Health Department Report, op.cit.* (note 45), 36.

62. Albert, *op.cit.* (note 59), 375.

63. Metropolitan Asylums Board Annual Report 1901, Sixteenth Report of the Statistical Committee. (London: McCorquadale & Co. Ltd., 1902).

64. *Ibid.*, 108.

(1786 notified cases), with a recrudescence period between January and May 1902 (469 notified cases).⁶⁵ The Glasgow epidemic terminated prior to the onset of the Boston epidemic and the two are unlikely to have been directly related. A small epidemic occurred in Dublin in 1903 with less than 250 cases and under 40 deaths,⁶⁶ which resulted from indigenous transmission with an index case from Glasgow. Vessels from Boston did not sail via Dublin (see Figure 4 below).

4. Transatlantic sailings transmitting smallpox from the Eastern United States to Liverpool

In the nineteenth century thousands of emigrants from the British Isles left from Liverpool Port. Packet lines sailed regularly from 1818, and in 1822 smallpox was transmitted from Liverpool to Baltimore on board the ship *Pallas*.⁶⁷ Demand for North American timber and cotton to meet British industrial expansion led to well established transatlantic links. British manufactured products provided a useful return cargo. Steamships started to replace sail after the 1860s and average voyage time was reduced to as little as six days.⁶⁸ The city of Liverpool was largely dependent upon the sea for its commercial prosperity. Several steamship lines at the turn of the century were competing for transatlantic passengers to Boston from Liverpool, and American cattle ships departing from Boston traded regularly with the City.⁶⁹ Schedules of ships arriving in Liverpool from Boston for different steamship companies resulted in multiple arrivals each week, and round trip transits took less than a month. In 1902 tonnage entering and leaving the river Mersey amounted to the colossal total of 29,000,000 tons, with 214,000 emigrants.⁷⁰

Prior to the 1901-1903 epidemic, smallpox was imported on eight known occasions to Liverpool in 1900, the most important being that of the *SS New England* which arrived with nineteen cases on board. This ship left Boston on 1 February, arriving in Liverpool on 30 March. On leaving Boston with 525 passengers and 268 crew, including fifty-five clergymen and many elderly people, it travelled to the Mediterranean.⁷¹ On 11 March, prior to arriving in Constantinople, a male death occurred after presenting with petechial skin haemorrhages which were attributed to liver atrophy.

65. Archibald Kerr Chalmers. *Smallpox, 1900 -1902* (Glasgow: Corporation of Glasgow Report, Printed by Robert Anderson, West Nile Street, Glasgow, 1902), 8-10.

66. Detailed annual reports of the Registrar- General (Ireland), for 1902 (39th), 1903 (40th), 1904 (41st) containing numbers and causes of deaths registered in Ireland for that year (His Majesty's Stationery Office, Dublin, printer Cahill and Co., Dublin, 1903,1904,1905).

67. Cyril William Dixon. *Smallpox*, (London: Churchill Press, 1962), 198.

68. The Liverpool Post, *The American Mails. Performances Outward and Homeward, Cunarders at the front*, April 11, 1900.

69. Edward William Hope. *Annual Report on the Health of the City of Liverpool during 1901* (Liverpool: C.Tinling and Co., Printing Contractors, 1902), 39.

70. Thomas Clarke. *Introductory address to the Section on Port Sanitary Administration*, Royal Institute of Public Health Congress, Liverpool, July, 1903. *Journal of State Medicine*, 11, 8 (1903), 454 – 461.

71. Port of Liverpool, *Annual Report of the Medical Officer of Health to the Port Sanitary Authority for the year 1900* (Liverpool: C. Tinling and Co., Printing Contractors, 1901), 16-17.

The body was buried at sea. By 21 March twelve other people were sick, including eight crew, two of whom were employed in the laundry, and two had been assigned to seal the dead man's body in a casket. By 23 March other passengers were sick with presumed malarial fever and biliousness, and some passenger deaths were reported, following visits to Jaffa and Naples. The Captain's log only records smallpox after 22 March, and it is unclear why he sought smallpox vaccine for himself on the eleventh while docked in Constantinople. The ship's doctor had no previous experience of smallpox. At Naples all remaining 500 passengers were peremptorily disembarked and given tourist tickets, while the vessel left port and sailed for Liverpool without communicating with them on the nature of this disease outbreak. The United States Marine Hospital Fortnightly Gazette reported that a number of these passengers fell ill with smallpox at Naples and in other places in Italy and France.⁷² Three persons subsequently developed the disease in Liverpool on dates which indicated it was contracted prior to disinfection of the ship, which occurred later at Liverpool. On 8 July 1900 the *SS Ivernia* from Boston also landed a single smallpox case at Queenstown while *en route* to Liverpool.

Competitive, fast transatlantic passenger and mail steamers were efficient disease vectors. Figure 3 illustrates three examples of transit involving two ships arriving during the initial phase of the Liverpool epidemic.⁷³ These ships left Boston during the period of peak prevalence during the epidemic of 1901 -1903.

[Place figure 3 near to here]

Dates in Figure 3 indicate when notified and not when the illness began. The *SS Kansas* arrived in Boston on 15 January following one smallpox death at sea. The ship was quarantined but the vessel was allowed to leave for its return trip to Liverpool after only 6 days. When it arrived back in Liverpool nine clinical cases were identified on arrival and transferred to the Port Sanitary Hospital at New Ferry, one of whom died.⁷⁴ The crew had been vaccinated before leaving Boston but some were already incubating the disease. The Boston Health Department Chairman, Dr Samuel Durgin, received criticism in the press for allowing the ship to depart after so few days of quarantine.⁷⁵ At a legislative hearing on an anti-vaccine bill he responded as follows to a critical heckler: 'I hold the public health of Boston in one hand and its commerce in the other.'⁷⁶ Commercial interests in Boston were influential factors affecting public health regulations, at least in this instance. The Health Department deliberately gave the outbreak a low profile to prevent an unwanted scare. Press releases stated alarm was needless and claimed smallpox has never been epidemic in the city.⁷⁷

72. *Ibid.*, 17.

73. Edward William Hope, *Annual Report on the Health of the City of Liverpool during 1902* (Liverpool: C.Tinling and Co., Printing Contractors, 1903), 26-51.

74. Port Sanitary Hospital, *op.cit.* (note 30). These men had different occupations, including baker, engineers, firemen, carpenter, sailor and boatswain.

75. The Boston Globe, *Eight cases on board*, February 7, 1902, 4.

76. Wallach, *op.cit.* (note 11), chapter three, *The 1901-2 smallpox epidemic in Boston and Cambridge*, 61.

77. The Boston Globe, *Alarm was needless. Smallpox has never been epidemic here. Less than two cases in every 3000 of the population of Boston*, December 15, 1901

The *SS Devonian* carried infected seamen on separate occasions in early December, January and February. With mild type illness the diagnosis was unclear until medical advice on skin spots was sought.⁷⁸ A further maritime case was identified on the *SS Campania* arriving from New York on 5 April, on a ship holding the fastest transatlantic crossing time.⁷⁹ Multiple secondary Liverpool cases arose from these infected seamen, especially through local lodging houses and contact with workhouse inmates. Seven different ships were carrying infected passengers, and the *SS Kansas* imported nineteen cases from Boston that were admitted to the New Ferry hospital. When the ship sailed from Liverpool on 4 January 1902 two crew were treated at sea, one of whom died. Late acquisition of smallpox explained these cases. Reaching Boston as many as twenty men were put ashore and all cattlemen were taken to the quarantine station and re-vaccinated.⁸⁰ Returning to Liverpool after leaving Boston the *SS Kansas* put back to New York and landed several further crew suffering from smallpox. Later arriving at Liverpool on 6 February nine convalescents and two contacts were identified and removed to the Port Sanitary Hospital.⁸¹ Most of the crew were re-vaccinated and some kept under close observation.

[Place figure 4 near to here]

Figure 4 shows the commercial trade connections of the Port of Liverpool and the multiple potential routes for inward transmission of smallpox in 1903⁸². Vessels from Liverpool travelling west to Boston discharged first at St Johns, Newfoundland, and Halifax, Nova Scotia. On the return journey these vessels often travelled directly to Liverpool. Between 1901 -1902 only a single case of smallpox was reported in Halifax affecting a seaman on a schooner leaving Gloucester, north of Boston.⁸³ No deaths from smallpox were reported in St Johns during this period,⁸⁴ which suggests westward transmission of smallpox from Liverpool was negligible. The number of maritime cases of smallpox landed from vessels in the Port of Liverpool between 1900 and 1904 is shown in **Table I** in relation to port origin and case fatality. The total number of identified cases arriving from Boston represents twenty-seven per cent of all maritime cases. The months involved are shown in detail in Figure 5, to illustrate occurrence in Liverpool and steamship arrivals from Boston with diagnosed smallpox infected crew or passengers. Another twenty-seven per cent of importations arrived from

78. The Liverpool Echo, *Smallpox in Liverpool, a fresh case reported today. Forty-two cases in the City*, February 17, 1902, 5.

79. The Liverpool Daily Post, *The American Mails, performances outward and homeward. Cunarders to the front, April 11, 1900*, 3.

80. Hope, 1903, *op.cit.* (note 73).

81. The Liverpool Daily Post, *The Smallpox, Liverpool, no fresh cases, infected Cattlemen removed to hospital*, Saturday, February 8, 1902, 6.

82. City of Liverpool. *Handbook compiled for the Royal Institute of Public Health, Liverpool Congress, 15 -21 July, 1903*, edited by E.W.Hope (Liverpool, Lee and Nightingale, Printers).

83. Alvey A. Ade. A case of smallpox on schooner Thalia at Halifax. *Public Health Reports*, 16, (1901), 2176.

84. St Johns, Newfoundland. Register of Deaths St Johns City District, Book 3 (1901-1902), 333-339.

New York and Baltimore in 1903 and 1904. Other in-coming vessels from outside the United States were also responsible for importations of cases or suspected cases of smallpox (Table I), but the majority of single country origin were from the United States.

[Place figure 5 near to here]

5. Maritime and non-maritime spread of smallpox in the United Kingdom 1901-1905

The connexion between seaports and smallpox had been initially observed in England in the epidemic of 1870 -1872, when Liverpool and London were the first places to feel the effects of the continental outbreaks associated with the Franco-Prussian war. In Liverpool smallpox had been introduced by Spanish sailors.⁸⁵ Liverpool experienced almost 2000 deaths in the 1871 epidemic, but these numbers decreased with 685 deaths during the 1876 -1877 epidemic and 34 deaths in the smaller 1881 epidemic.⁸⁶

The 1901 Liverpool outbreak was the last major smallpox epidemic in this city. Its magnitude was comparable to earlier 1876 - 1878 outbreaks, as shown in Figure 6. Four Liverpool epidemics had

[Place figure 6 near to here]

occurred between 1875 and 1896, which exactly corresponded temporally with the London epidemics, spanning both the same years and having identical epidemic periods. This suggests indigenous transmission between these cities. In contrast, the Liverpool epidemic of 1901 commenced twelve months after onset of the London epidemic and was characterised by milder infections and close association with imported maritime cases. Yet in London, during 1902, of ninety-three smallpox cases treated in their Port Sanitary Hospital, only one was an imported infection from New York, admitted on 12 April from the *SS Minnehaha*.⁸⁷ Other cases were internally transferred to London, mostly from British Ports - particularly Newcastle, with additional single importations from Spanish, German, and Dutch ports, as well as India and South Africa.⁸⁸

John Christie McVail (1849-1926), Medical Officer of Health for Stirling and Dumbarton in Scotland, and a leading advocate of smallpox vaccination in the early twentieth century, suggested that smallpox was no longer indigenous in the United Kingdom and insisted that epidemic outbreaks were imported.⁸⁹ He tabulated provincial smallpox outbreaks in English and Welsh cities and towns between 1902 and 1905.⁹⁰ Incidence estimates per capita can be derived from these case numbers using the 1901 United Kingdom National Census. These are listed in **Table II**, and their spatial dispersion mapped in Figure 7. Case fatality estimates are also tabulated for the same locations.

[Place figure 7 near to here]

85. Hardy, *op. cit.* (note 13), 128 and 132.

86. *Ibid.*, 128.

87. Port of London Sanitary Committee. *Annual Report of the Medical Officer of Health to 31 December 1902*. May 1903, appendix H, 83.

88. *Ibid.*, appendix H, pp.77-91.

89. McVail, *op cit.*, (note 49), 8, 26.

90. *Ibid.*, p.6 (Table II).

The Liverpool focus is distinct from those in Glasgow, London, Edinburgh, Tynemouth, Hull and South Wales, which are all ports, but which did not have regular scheduled transatlantic links with Eastern United States seaports. In Southampton only two cases of smallpox were reported on vessels bound for the Port in 1902.⁹¹ Smallpox outbreak distribution shows temporal dispersion across North-West and Central England between the years 1902 and 1904. The dispersion pattern implicates Liverpool as the primary focus possibly with discrete sequential transmission across the North-West during these years. In these outbreaks, case fatality was low or very low (Table II) and in the North-West averaged 6.3%. This mortality was much lower than in the 1901 London epidemic (21.6%) suggesting infection was mostly due to a different milder strain, consistent with transmission mainly from the Liverpool focus where a mild strain of *Variola minor* was dominant. Chapin had considered it highly probable that the mild type of smallpox was carried to England from Boston in 1902 and during the following years.⁹² Case fatality during the epidemic decreased from around sixteen per cent in 1901 to eight per cent in 1903.⁹³ As all cases were hospitalised this may have caused a bias towards observing severe or fatal cases.⁹⁴ More than half the national deaths from smallpox in 1902 occurred in the north-west of England, either in Lancashire or in the contiguous West Riding of Yorkshire. In both cases, about four-fifths of the mortality took place in the course of the first half of the year with the majority of deaths in the city of Liverpool.⁹⁵

The first infected Liverpool resident was identified on 12 December 1901 (Figure 3), from a lodging house ‘infected’ by an imported maritime case.⁹⁶ Between December 1901 and November 1902 there were three minor epidemics, followed by a major epidemic between December 1902 and December 1903. The minor epidemics corresponded temporally to the period of initial importation of Boston cases (Figure 3). The onset of the ensuing major epidemic corresponded with the second peak in prevalence in Boston. Indigenous Liverpool cases who had some direct or indirect contact with Boston seamen can be identified up until January 1903. Between October 1902 and December 1903, 108 households reported cases which accommodated sailors or mariners.⁹⁷ Imported cases from other East coast American ports were recorded in 1903 (Table I). Smallpox was circulating in other British

91. Southampton 1902 *Public Health Report*, 26.

92. Chapin, *op cit.*, (note 3).

93. *Annual Reports on the Health of the City of Liverpool during 1900 to 1904*. (C. Tinling and Co., Printing Contractors, Liverpool 1901). Estimates compiled from figures available from Annual Health Reports produced by Dr EW Hope, Medical Officer of Health for Liverpool, for the years 1900 to 1904, and published in the years 1901, 1902, 1903, 1904, and 1905.

94. Martin Eichner. Analysis of historical data suggests long-lasting protective effects of smallpox vaccination. *American Journal of Epidemiology*, 158, (2003), 717-723.

95. *Sixty-sixth Annual Report of the Registrar-General of Births, Deaths, and Marriages in England and Wales (1903)*. (His Majesty’s Stationery Office, London: Darling and Son, Ltd., 1905), xviii.

96. *Report by Dr Richard J. Reece to the Local Government Board on smallpox and smallpox hospitals at Liverpool, 1902 -1903* (London: His Majesty’s Stationery Office, Darling and Son Ltd., 1905), 10.
<https://search.wellcomelibrary.org/iii/encore/record/CRb2136004>.

97. Edward William Hope, *Annual Report on the Health of the City of Liverpool during 1903*, (Liverpool: C. Tinling and Co., Printing Contractors, 1904), 32.

ports, and internal transmission via English coastal shipping cannot be ruled out as these ports did not have Port Sanitary Stations and were not subject to the same surveillance as in Liverpool.

Figure 8 shows the temporal associations of the New York, Boston, Glasgow, London and Liverpool epidemics between 1900 and 1903. Incidence is estimated using population denominators from the United States 1900 census and British 1901 census.^{98,99} All epidemic periods (time of onset to time of resolution) shown in Figure 8 are less than two years. The Liverpool and Boston epidemics covered almost identical periods (Liverpool, twenty-four months; Boston, twenty-three months), although the shape and distribution of the monthly totals are dissimilar. Peak incidence per 100,000 population was very similar in Boston and Liverpool. Marked left-sided skewness is evident for the Liverpool and Glasgow epidemics, suggesting low early transmission rates. The source of the Glasgow outbreak was attributed to severe smallpox in a seaman on board the *SS Hispania* which arrived from Bombay.¹⁰⁰ Left-sided skewness was not evident in the London outbreaks in which maritime importations were considered less critical. This conclusion is supported by Hardy who has commented that for previous London epidemics:

*'In 1881, although smallpox was epidemic in the metropolis, the cases occurring in the port were few in number and "quite isolated". There were six imported cases. The smallpox epidemics occurring in London in 1876, 1881, and 1884 cannot with certainty be traced to infection from abroad: it is possible that the strain introduced in 1870 was working itself out with diminishing virulence, and that the port sanitary authorities were successful in preventing its refreshment from abroad,'*¹⁰¹ and:

*'In December 1876 the Port Medical Officer reported that although smallpox was widely epidemic in London, it had so far manifested itself in the floating population to an infinitesimal extent.'*¹⁰²

[Place figure 8 near to here]

The resolution of the Liverpool epidemic was rapid, with a marked fall in incidence in June 1903, which compares to a much slower resolution in Boston over several months. As described below, this may relate to differences between the two cities in the effectiveness of the public health response, epidemiological approaches to disease control, as well as the lower vaccine uptake in Boston and staggered introductions of vaccine delivery. Case fatality in unvaccinated persons in Boston was very similar to that in Liverpool (Table III), whereas fatalities in unvaccinated persons in the London and Glasgow epidemics were double that of Boston and Liverpool. It is therefore likely this was predominantly a milder illness consistent with a *Variola minor* strain in Boston and Liverpool, whereas the higher case fatality in unvaccinated cases in London and Glasgow is consistent with *Variola major* as the primary source of infection.

98. United States National Census, 1900, *op.cit.* (note 47).

99. United Kingdom National Archives, 1901 Census.

100. Chalmres, *op.cit.*, (note 65), 9.

101. Hardy, *op.cit.* (note 13), 132, and *Half-Yearly Report of the Medical Officer*, (Port of London, June 1881), 4.

102. *Ibid.*, p 132, and *Half-Yearly Report of the Medical Officer*, (Port of London, December 1876), 9.

6. Other factors influencing the course of the Boston and Liverpool epidemics

Public health measures and quarantine

It is now known that smallpox can have a long incubation period (up to 22 days),¹⁰³ and a relatively low infectious rate without close direct contact, which would cause it to spread slowly within or between communities.¹⁰⁴ In 1902 the incubation phase was less well defined, and containment strategies for asymptomatic contacts who were potentially incubating the disease varied. In both Boston and Liverpool emphasis on land was on search and containment. Outbreaks were aborted by vaccination around each focus, but contacts were not necessarily placed in quarantine. In Boston, houses were kept under observation by medical inspectors for fourteen days with removal of secondary cases, but contacts were free to travel, even if they refused vaccination. The absence of quarantine led to heated exchanges published in the *Cambridge Chronicle*, in which the Mayor and the state Medical Board doctor recommended quarantine, whereas the Board of Health opposed it.¹⁰⁵ Health authorities in some towns recommended quarantine for immigrants or migrant workers. Men living in inexpensive rooming houses were ordered to be vaccinated by the Boston Board of Health¹⁰⁷, but it allowed settled inhabitants their freedom. Quarantine was outrageously expensive and health departments that relied on vaccination alone justified this as efficiency and fiscal responsibility.¹⁰⁸ Whether to quarantine or vaccinate thus involved social, economic, and cultural considerations.

In the United Kingdom the Scottish obstetrician Sir James Young Simpson (1811-1870) wrote an influential outline on smallpox prevention based on household isolation policies. Its departure point was early case notification, quarantine of infected patients, vaccination of carers, hygienic cleaning of everything in contact with the patient, and strict disinfection and bedding procedures.¹⁰⁹ Households were to be fumigated by burning sulphur for five hours, stripping and burning wallpaper and spraying the interior with mercury perchloride solution, with up to thirty-four houses treated daily.¹¹⁰ These practices were regularly followed in Liverpool during the 1901 epidemic but isolation of contacts was less straightforward and opinions were divided on whether smallpox was transmitted in the prodromal phase of the illness when the patient was febrile, but had no rash – the main

103. Nishiura, *op cit.* (note 10). The ninety-nine per cent upper confidence limit of the incubation period is 22.2 days suggesting that quarantine should last 23 days.

104. James A Yorke, Neal Nathanson, Giulo Pianigiani, John Martin. Seasonality and the requirements for perpetuation and eradication of viruses in populations, *American Journal of Epidemiology*, 109,2 (1979), 103-123.

105. Wallach, *op.cit.* (note 11), 152-153.

106. *Cambridge Chronicle*, *Mayer McNamee scores a point*, *Cambridge Chronicle*, July 12, 1902, 1; *Smallpox scourge*, June 21, 1902; *Dr A.W.Bowman takes issue with other physicians and the Board of Health*, August 9, 1902, 6.

107. Albert et al, *op.cit.* (note 59), 375-376.

108. Wallach, *op cit.* (note 11), 68-69.

109. James Simpson. *A proposal to stamp out smallpox*, Edinburgh: Edmonton and Douglas, 1868.

110. Reece, *op cit.*, (note 96), 2-3.

indicator for virus transmissibility. Ships with on board crew in a vessel infected with smallpox were not routinely quarantined since the Public Health Act of 1896 did not require this, and detention for longer than thirty-six hours was considered unreasonable.¹¹¹ In fact, apparently healthy passengers could disembark from their ships without knowing they were transmitters. Cattlemen from Boston sometimes sold their return passage tickets, remaining in Liverpool lodging houses, and often in particular streets and the poorer districts.¹¹² This together with misdiagnoses due to the uncharacteristic rashes related to milder illness, meant that containment and contact tracing were only partially successful. Epidemic proportions of infection first occurred in Liverpool in areas such as Everton, having insanitary housing awaiting demolition, many of which were over-crowded, and had the highest case fatality.¹¹³ Homeless tramps were also blamed for spreading infection in Liverpool,¹¹⁴ as were vagrants during the Boston epidemic.¹¹⁵

Views on modes of transmission that affected the public health response

In the late nineteenth-century the mode of transmission of smallpox was not well understood. It was considered intensely infectious, arising potentially from aerosol spread, infected fomites and direct contact with the patient, their clothing or belongings. In industrialised countries it was considered a ‘winter disease’¹¹⁶ because even short-term epidemics clearly exhibited an annual peak in January. An analysis by Sir Leonard Rogers (1868 – 1962) of the mild type of smallpox in England and Wales from 1921 to 1927 showed peak seasonal prevalence, closely related to low absolute humidity and lower temperatures.¹¹⁷ Peak prevalence in Boston in 1901 was in January, and in Liverpool covered the months January to March in 1903. A similar monthly pattern was observed in Glasgow and London (Figure 8), although the possible seasonal pattern remains unexplained for this period.

The smallpox register for Liverpool queried whether two cases had occurred from contact with foreign mail.¹¹⁸ Sir William Osler (1849-1919), a young Canadian physician in 1876, had disinfected his letters when he had smallpox,¹¹⁹ and in his popular 1892 general textbook of medicine he supported the fomite transmission theory. The British Medical Journal in 1901 reported

111. Clarke, *op cit.*, (note 70), 458.

112. The Liverpool Daily Post, *Smallpox in Liverpool. The conscientious objector’s clause, suggested repeal*, January 31, 1902, 7.

113. *Ibid.*, January 31, 1902.

114. Edward William Hope, *Annual Report on the Health of the City of Liverpool during 1903*, (Liverpool: C. Tinling and Co., Printing Contractors, 1904), 24.

115. Albert et al, *op.cit.* (note 59), 375-376.

116. Hiroshi Nishiura, T. Kashiwagi. Smallpox and season: reanalysis of historical data. *Interdisciplinary Perspectives in Infectious Disease*. 2009; 2009:591935. doi: 10.1155/2009/591935.

117. Sir Leonard Rogers. Smallpox and climate in England and Wales. *BMJ*, 1, February 25, (1928), 300-302.

118. Liverpool Smallpox Register, *op.cit.* (note 30).

119. C.T.Ambrose. Osler and the infected letter. *Emerging Infectious Diseases*, 11, 5 (2005), 689-693.

smallpox transmission to Nottingham by Mormon mail from Salt Lake City,¹²⁰ where it was unlawful to compel vaccination.¹²¹ Transatlantic steamers were the only means of mail transportation from North America but there is no evidence of disinfection procedures involving mail.

A major concern was infection of communities living in proximity to isolation hospitals, including the New Ferry Hospital. Confusion over aerial transmission, and in particular, controversy over spread of disease from hospitals was a major concern,¹²² and was a reason the Liverpool outbreak was studied in great detail.¹²³ This issue was investigated by Dr Richard J. Reece and reported in a memorandum to the Liverpool Medical Officer of Health in 1905.¹²⁴ Following detailed statistical analysis he concluded that smallpox risk was disproportionately high in areas nearer to the hospital during periods in which it was receiving acute smallpox cases. This conclusion was queried by Dr Edward William Hope (1856-1951), the Medical Officer of Health for Liverpool, who listed ten points of contention, noting that high numbers of cases also occurred around hospitals not receiving smallpox cases, and for one hospital, cases occurred before the receiving hospital was opened.¹²⁵ Although disputed,¹²⁶ Reece defended his conclusions, considering that aerial convection probably operated in the case of each Liverpool hospital.^{127, 128} Sixty years after these exchanges, community concerns about neighbourhood smallpox transmission in the vicinity of the Port Sanitary Hospital at New Ferry were still being voiced following incidence of residential infections within a quarter mile radius of the hospital.^{129 - 132} This concern was also expressed by the Chief Public Health

120. Philip Boobbyer, Smallpox in Nottingham, *BMJ*, 1(1901), 1054.

121. Willrich, *op cit.* (note 39), 276-278.

122. P. P. Mortimer, Ridding London of smallpox: the aerial transmission debate and the evolution of a precautionary approach. *Epidemiology and Infection*, 136, (2008), 1297-1305.

123. Derrick Baxby. Studies in smallpox and vaccination. *Reviews in Medical Virology*, 12, 4 (2002), 201-209.

124. *Ibid.*, (note 96).

125. Edward William Hope, *Observations of the Medical Officer of Health on the Report of Dr R.J. Reece to the Local Government Board on smallpox and smallpox hospitals at Liverpool, 1902-03*, ordered by the Port Sanitary and Hospitals Committee (Liverpool: C. Tinling and Co., 1905).

126. William Knollys, *On the 'Observations' of Dr Hope, Medical Officer of Health for the City of Liverpool, upon the Report of their Inspector, Dr Reece, on 'Smallpox and smallpox hospitals in Liverpool', and also on Dr Hope's previous report on smallpox in Liverpool*, William Edward Knollys, Assistant Secretary Local Government Board, Whitehall, Addressed to the Town Clerk, Local Government Board Liverpool. London: Whitehall, 11 August, 1905.

127. Mortimer, *op.cit.* (note 122).

128. *Memorandum by Dr R.J. Reece, as to questions raised by Dr Hope regarding his Report on smallpox and smallpox hospitals at Liverpool 1902-03*, Richard J. Reece, 6 July, 1905.

https://search.wellcomelibrary.org/iii/encore/record/C__Rb2136006.

129. *Bebington News and Advertiser*, Smallpox case renews 'move hospital' call, April 19, 1958, 1.

130. *Ibid.*, Disease spread by flies says ex-health chief, May 24, 1958, 5.

131. *Ibid.*, Residents irate at hospital board rebuff, forming committee of public safety, July 19, 1958, 1.

132. *Ibid.*, New Ferry smallpox hospital to be moved, September 13, 1958, 1.

Inspector at the time, who implicated fly transmission.¹³³ An airborne outbreak of smallpox in a German hospital was reported in 1970, which demonstrated the local features believed to be of importance in this unusual pattern of transmission.¹³⁴

Modern understanding has improved knowledge of infection risk, although the minimum infectious dose of smallpox remains unknown, ie how many virus particles an individual needs to inhale to become infected.¹³⁵ The probability of airborne tiny particles (less than a thousandth of a millimetre in size) from surfaces seems low because the smaller the particle the more avidly it adheres, reducing the risk of fomite transmission.¹³⁶ This issue was re-assessed as late as 1978 during the legal case surrounding the last case of smallpox in the United Kingdom, when long distance airborne spread of smallpox from a laboratory was dismissed as improbable.¹³⁷ A recent meta-analysis calculated that when index cases were quickly identified and control established early, the reproduction rate to secondary generations was low, which is consistent with limited aerial transmission. When index cases remained unidentified a large increase in the median initial reproduction rate occurred.^{138, 139} In the Liverpool epidemic a crude upper estimate of the reproduction rate (defined as the expected number of new infected hosts that an infectious host will produce in a large randomly mixed population of susceptible individuals), was up to twenty, based on index and secondary cases, suggesting late case recognition with a high reproduction rate.¹⁴⁰ This rate may be overestimated as contact status was not always available and tertiary or later generation cases may have been included. There may be an interval of two to three weeks between each generation of cases and even during the transmission season an index case rarely infected as many as five persons.¹⁴¹ Failure to instigate effective case isolation and contact tracing would have prolonged the Liverpool epidemic.

133. Bebington News and Advertiser, op.cit, (note 130).

134. Wehrle PF, Posch J, Richter KH, Henderson DA. An airborne outbreak of smallpox in a German hospital and its significance with respect to other recent outbreaks in Europe. *Bulletin of the World Health Organisation*, 43, 5 (1970), 669-79.

135. David H. Henderson. Smallpox epidemic models and response strategies. *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science*, 11, 1 (2013), 73-74.

136. Donald K. Milton. What was the primary mode of smallpox transmission? Implications for biodefense. *Frontiers in Cellular and Infection Microbiology*, 2 (2012), 150.

137. Mark Pallen, *The Last Days of Smallpox, Tragedy in Birmingham* (Independently published, 2018), 230.

138. Vibha Bhatnagar, Michael A Stoto, Sally C Morton, R. Boer, S.A. Bozette. Transmission patterns of smallpox: systematic review of natural outbreaks in Europe and North America since World War II, *BMC Public Health*, 6, (2006),126, doi:10.1186/1471-2458-6-126.

139. J. Bincer, H. Wysoczynska, B. Trzaska. Smallpox epidemic in Gdansk in 1962, *Przegl Epidemiology*, 19, 4 (1965), 421-31.

140. Martin Eichner. Case isolation and contact tracing can prevent the spread of smallpox. *American Journal of Epidemiology*, 158, (2003), 118-128.

141. F Fenner, DA Henderson, I Arita I, Z Ježek, ID Ladnyi. *Smallpox and its eradication. Epidemiology Section* (Geneva: World Health Organisation, 1988), 208.

Vaccine efficacy and uptake

Table III compares case fatalities in several cities in relation to vaccination status. Vaccine efficacy is estimated for each site. Vaccine efficacy in this context is the percentage reduction in case fatality in the vaccinated compared to the unvaccinated group. Such estimates were not reported at the time of the United States and United Kingdom outbreaks as an accepted formula for its calculation had not yet been proposed. Statistical methods to evaluate how likely it is that any observed difference between the groups arose by chance were first proposed in 1900 by Karl Pearson (1857-1936), founder of the modern field of statistics, using the chi square test.¹⁴² It was not until 1915 that epidemiologists derived measures related to efficacy.¹⁴³ Publications and reports on smallpox epidemics in the early twentieth century provided only descriptive statistics with listings of cases and deaths.¹⁴⁴⁻¹⁴⁶

From the estimates of vaccine efficacy in Table III, it can be concluded that it was considerably lower in Boston than Liverpool, reflected in the higher death rate of vaccinated cases in Boston. Mortality in unvaccinated cases was similar in both cities. Vaccine efficacy estimates for the London and Glasgow outbreaks were much higher than that for Boston. The proportion of the hospitalised population vaccinated in Boston was only twenty seven per cent, which was less than half that for the United Kingdom cities. Vaccine uptake in the United States was irregular,¹⁴⁷ and by the 1930s four states still had laws prohibiting compulsory vaccination, twenty-nine had no vaccine laws, six provided for a local option and four had made it compulsory.¹⁴⁸ In Boston, State law by 1855 required that children be vaccinated to enter public school but adult vaccination was voluntary. Yet enforcement was problematic and in 1902 there was uncertainty on how many people were vaccinated in Boston as no state or federal agency compiled data. In England infant vaccination had been compulsory since 1853, with substantial penalties for non-compliance in 1902.¹⁴⁹ In 1898 an amendment to the Public Health Act allowed conscientious objection, although early in the twentieth

142. Karl Pearson. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. *Philosophical Magazine*, Series 5, 50 (1900), 157–75.

143. Major Greenwood, G.U.Yule. The statistics of anti-typhoid vaccine and anti-cholera inoculations, and the interpretation of such statistics in general. *Proceedings of the Royal Society of Medicine (Section Epidemiology and Statistics Medicine)*, 8, (1915), 113-194.

144. Edward J. Edwardes. A century of vaccination: smallpox epidemics and smallpox mortality before and since vaccination came into use. *BMJ*, 2 (1902), 27 – 30.

145. W. R. MacDonnell. On the influence of previous vaccination in cases of small-pox. *Biometrika*, 1, 3 (1902), 375-383.

146. A. Rusnock. Medical statistics and hospital medicine: the case of the smallpox vaccination. *Centaurus*, 49 (2007), 337-359.

147. James Colgrove. Between persuasion and compulsion: Smallpox control in Brooklyn and New York, 1894-1902. *Bulletin of the History of Medicine*, 78 (2004), 349-378.

148. Hopkins, *op.cit.* (note 2), 293.

149. Mrs Garrett Anderson.. On the Administration of the laws for the prevention of epidemic smallpox. *BMJ*, 2, (1902), 30-32.

century less than 200,000 exemptions were granted, equivalent to about twenty-five per cent of all births.¹⁵⁰ In 1901 coverage of infants in England due to be vaccinated was approximately seventy-eight per cent.¹⁵¹

In both countries community wide vaccination and re-vaccination campaigns were started during the epidemics. In Boston uptake was impaired by the unpopularity of the vaccine, side effects seemingly a greater problem than mild smallpox.¹⁵² Massachusetts vaccination law also penalised vaccination refusal with a five dollar fine. In January 1902 legislation was proposed by anti-vaccination supporters, including some physicians, to repeal state compulsory vaccination laws.¹⁵³ The anti-vaccination campaign undermined public acceptance of Health Department authority as it disputed the utility of vaccination on medical grounds as well as based on restriction of civil liberties. The well recognised Boston physicians, Dr Caroline Eliza Hastings (1841-1922) and Dr Sarah Newcomb Merrick (b.1844), sparred with Dr Durgin, the Chair of Public Health, disputing the merits and safety of the vaccine.¹⁵⁴ This debate captured the ideological interface between antivaccinationists and public health. A focal point was the British Anti-vaccination League, which had strong links to New England.¹⁵⁵ In 1905 the United States Supreme Court eventually upheld the right that states could mandate compulsory vaccine laws under their police powers.¹⁵⁶ The story of these judicial proceedings highlights the critical role for medical authorities to gain public trust from a diverse audience in ensuring the success of a public health campaign. In England public concern about vaccination led to the introduction of the conscience clause in the new vaccination act.¹⁵⁷ In Boston intermittent vaccine availability from private and public sources, doubts about the efficacy of vaccine lymph, concerns about complications, including documented contaminated vaccine transmission of syphilis and tetanus, compounded public anxiety such that public confidence plummeted.¹⁵⁸ There were staggered introductions of vaccinations programmes, with closures and re-

150. Nadja Durbach. *Bodily matters. The anti-vaccination movement in England, 1853-1907*. (Durham (NC), Duke University Press, 2005), 10.

151. E.P.Hennock. Vaccination policy against smallpox, 1835-1914: a comparison of England with Prussia and Imperial Germany. *Social History of Medicine*, 11 (1998), 49-71.

152. Albert, *op.cit.* (note 59), and The Boston Globe. Hearing Over, 5 February, 1902, 4.

153. Wallach, *op cit.*, (note 11), 6-7, 102-126, 146-162. Wallach outlines the 1902 campaign to amend the compulsory vaccination laws and the conflict between the anti-vaccinationists and Dr Samuel Durgin, Chair of Public Health. The Massachusetts state legislature went back and forth on the issue of compulsory vaccination for several years, but in 1914 amended the law to allow unvaccinated children admission to public schools if their parents opposed vaccination (Wallach, 216).

154. *Ibid.*, 116-120.

155. Parmet WE, Goodman RA, Farber. Individual rights versus the public's health--100 years after *Jacobson v. Massachusetts*. *New England Journal of Medicine*, 352, 7, (2005) 652-4.

156. The background and history of this judicial court activity are discussed in detail in Wallach, *op cit.*, (note 11) chapter nine, *Jacobson versus Massachusetts*, 187-214.

157. Dorothy Porter and Roy Porter. The Politics of Prevention: Anti-Vaccinationism and Public Health in Nineteenth-Century England. *Medical History*, 32, (1988): 231-52.

158. Wallach, *op cit.* (note 11), 84-88.

opening of vaccine stations in Boston and Cambridge.¹⁵⁹ It is likely these factors contributed to the length of the post peak epidemic period that occurred in Boston.

In Liverpool widespread smallpox vaccination was prioritised and the benefits of vaccination were strongly promoted locally.¹⁶⁰ The question of effectiveness arose due to cases occurring in known vaccinees, and it was understood that primary vaccination alone would not prevent severe epidemics.¹⁶¹ Some individuals used the conscientious objection clause in the 1898 Public Health Act to refuse vaccination. During the epidemic, the Medical Officer of Health for Liverpool supported an initiative to repeal this clause,¹⁶² stating that 460,000 people remained susceptible out of a population of 750,000 (sixty-one per cent).¹⁶³ This is lower than the estimate in Table III, derived from hospital data. With coverage thus reduced, medical officers had also to rely on public health surveillance and containment, with selective vaccination of contacts.¹⁶⁴

The reasons for higher vaccine efficacy in Liverpool compared to Boston are unknown. This may relate to vaccine potency or storage conditions, differing pre-epidemic population immunity, or herd immunity,¹⁶⁵ and/or strain variations in smallpox virus.¹⁶⁶ Boston and Liverpool authorities produced different vaccines derived from varying strains. Badcock's lymph was generally used in England,¹⁶⁷ and Mulford's pure lymph vaccine in the East coast United States.¹⁶⁸ Bacterial contamination became a problem in the United States in 1901-1902 when the demand for vaccine was great, perhaps indicating haste in production.¹⁶⁹ Vaccine production was poorly regulated, with competition between several private firms. In 1895, Walter Reed (1851-1902), the eminent United States army pathologist and bacteriologist, had presented a paper to the District of Columbia Medical Society

159. The Boston Globe, *New Stations opened on Huntington Ave*, November 19, 1901; *Lull in vaccination*, December 8, 1901; The Cambridge Chronicle, *Dr A.W. Bowman takes issue with other physicians and the Board of Health*, August 9, 1902, 6.

160. The Birkenhead and Cheshire Advertiser and Wallasey Guardian. *Smallpox at New Ferry, Reassuring statement by Dr Kenyon*, 1 February, 1902, 8.

161. Edward J. Edwardes. *A Concise History of Smallpox and Vaccination in Europe*. (London: Lewis, 1902), 133.

162. The Liverpool Daily Post, *op.cit.* (note 112).

163. The Liverpool Daily Post, *Is vaccination efficient? Value and defects*, 1 February, 1902, 6.

164. Hennock, *op.cit.* (note 150).

165. H.Nishiura, K.Dietz, M.Eichner. The earliest notes on the reproduction number in relation to herd immunity: Theophil Lotz and smallpox vaccination. *Journal of Theoretical Biology*, 241, (2006), 964-967.

166. Clarissa Damaso. Revisiting Jenner's mysteries, the role of the Beaugency lymph in the evolutionary path of ancient smallpox vaccines. *Lancet Infectious Diseases*, 18, (2018), e55-63.

167. Williams, *op.cit.* (note 42), 270.

168. Livia Schrick, Clarissa Damaso, José Esparza, Andreas Nitsche. An early American smallpox vaccine based on horsepox *The New England Journal of Medicine*, 377, (2017), 15-16.

169. M.J.Rosenaau. The bacteriological impurities of vaccine virus. An experimental study. Hygienic Laboratory Bulletin No 12, March 1903. Public Health and Marine-Hospital Service of the United States (Washington Government Printing Office, 1903).

titled 'What credence should be given to the statements of those who claim to furnish vaccine free of bacteria'.¹⁷⁰ His answer, after examining vaccine needle points, was 'none at all'.¹⁷¹ By early 1902 the medical profession realised that national licensing was required as it was contradictory to require compulsory vaccination without product safety. An Act of Congress was signed by President Theodore Roosevelt on 1 July, 1902 requiring manufacturers to comply with production standards, after which four firms went out of business.¹⁷²

Vaccine virus deteriorates if not cooled in transit, and transport in baggage cars in the United States had to avoid proximity to steam coils which affected vaccine quality.¹⁷³ In Liverpool, Dr William Hanna, assistant Medical Officer of Health for Liverpool, noted that below freezing temperatures could easily be obtained on board most larger sea vessels, and a suitable supply of efficient lymph (ie vaccine) could be stored for months and be ready in an emergency.¹⁷⁴ Lack of available vaccine aboard oceanic vessels remained an important limitation.

In theory vaccination not only diminishes the susceptibility of vaccinated individuals, but also reduces the degree and duration of infectiousness.¹⁷⁵ In Liverpool only a few vaccinated children less than five years of age developed smallpox, indicating protection following infant vaccination that lasted longer than five years.¹⁷⁶ An assessment of vaccination during the Liverpool epidemic was presented almost a decade later by Dr Hanna in a book entitled 'Studies in Smallpox and Vaccination'.¹⁷⁷ Post exposure vaccination of contacts early in the incubation period was recommended. This strategy of selective ring vaccination of contacts living proximate to cases which was used in Liverpool was adopted during the World Health Organisation smallpox eradication campaign of the 1970s. Despite challenges by the Anti-vaccination League.¹⁷⁸ Liverpool remained one of the best vaccinated cities in the country.¹⁷⁹

170. Walter Reed was a United States army physician who won fame in 1901 leading the team that postulated and confirmed the theory that yellow fever is transmitted by a particular mosquito species, rather than by direct contact.

171. Willrich, *op cit.* (note 39), 184.

172. Editorial. Government Control of Vaccine Virus. *Journal of the American Medical Association*, 43, 26 (1904), 1974.

173. *Ibid.*, 1974.

174. Hanna, *op.cit.* (note 32), 24.

175. Hiroshi Nishiura, Stefan O. Brockman, Martin Eichner. Extracting key information from historical data to quantify the transmission dynamics of smallpox. *Theoretical Biology and Medical Modelling*, 5, (2008), 20.

176. Eichner, *op.cit.* (note 94), 719-721.

177. William Hanna. *Studies in Smallpox and Vaccination* (London: Wright and Sons, 1913).

178. *Studies in Smallpox and Sanitation based on the experience of the City of Liverpool. A reply to the book entitled 'Studies in smallpox and vaccination' by William Hanna.* (The National Anti-Vaccination League, Strand, London, 1913).

179. In the Annual Report for 1885 the then Medical Officer of Health, Dr J. Stopford Taylor, estimated that ninety-two per cent of the people of Liverpool were more or less efficiently vaccinated. His successor, Dr E.W.Hope, said that there were grounds for supposing that Liverpool was amongst the best vaccinated communities in the country.

Press responses

Two Liverpool city newspapers printed regular press communications, with occasional notices in the local Wirral Birkenhead press, which covered the New Ferry Sanitary Hospital area. The press was responsible for reporting accurately the local position. Detailed summaries of medical presentations by Dr Edward Hope, held at The Liverpool Medical Institute, were printed for public consumption, and included conclusions of local City Council meetings.¹⁸⁰ Newspapers promoted vaccination and emphasised epidemic surveillance by reporting case numbers, which must have reassured the general public. It was less alarming to attribute new cases to maritime sources than to discover a local source of contamination.¹⁸¹ Local opposition remained and prominent individuals opposed to vaccination published their views in the national press, including George Bernard Shaw (1856-1950).¹⁸² Spurious claims appeared in *The Liverpool Echo* for use of alternative remedies, such as a ‘curative syrup’ (Mother Seigels) in times of epidemic, that would keep the whole body strong, avoiding enfeeblement by indigestion, anaemia, blood disorders and lack of stamina necessary to resist contagion.¹⁸³ A qualification noted ‘Mother Siegel’s Syrup does not cure smallpox, but will purify the blood, build up the system and give increased strength to resist contagion and disease’.

Multiple press news releases appeared in the *Boston Globe* and *Cambridge Chronicle* as the outbreak developed. The *Globe* reported in December 1901 that the outbreak had abated, was at no time serious, and that the public seemed to have been needlessly alarmed with largely imaginary dangers.¹⁸⁴ Disputes on conflicting medical advice were published, and prosecutions for refusing vaccination, as well as the official advice of the Massachusetts Anti-compulsory Vaccination Society,¹⁸⁵ together with illustrations of the public campaign to promote vaccine uptake.¹⁸⁶ As in Liverpool, advertisements encouraged people to seek protection from other means, including ‘Radam’s microbe killer’ that prevented and cured every contagious disease,¹⁸⁷ and Lifebuoy Soap that prevented smallpox.¹⁸⁸ Howard’s Health Company cures were advertised in a journal started in November 1901 by the anti-vaccination campaigner Dr Immanuel Pfeiffer of Boston,¹⁸⁹ who became infamous in February 1902 when, unvaccinated, he contracted smallpox after visiting Boston’s smallpox hospital on a dare from Dr Durgin, Boston’s Board of Health Director.¹⁹⁰

180. *The Liverpool Daily Post*, *op.cit.* (note 112).

181. *The Liverpool Daily Post*, *Smallpox in Liverpool, traceable to original source*, 5 February, 1902, 4.

182. George Bernard Shaw, Mr Bernard Shaw on smallpox prevention, *BMJ* 2 (1901), 1289-1291.

183. *The Liverpool Echo*, Advertisement, Thursday, 16 January, 1902, 3.

184. *The Boston Globe*, *op cit.* (note 75), *Alarm was needless*.

185. *The Cambridge Chronicle*. *Anti-vaccination*. March 29, 1901.

186. Albert, *op.cit.* (note 59), 378, Figure 3.

187. *The Boston Post*. Radam’s Microbe killer advertisement, 4 December 1901, 7.

188. *The Cambridge Chronicle*. Lifebuoy soap advertisement, 28 June 1902, 3.

189. Wallach, *op cit.* (note 11), 84.

190. This episode is outlined in Wallach, *op cit.*, (note 11): Immanuel Pfeiffer versus the Boston Board of Health, 127-145.

The demise of smallpox

The data presented above support the view that, in the late nineteenth and early twentieth century, smallpox had become a disease primarily introduced to the north of England from abroad by merchant seamen or by travellers. Sometimes the disease was detected on board ship, but inadequate public health measures lead to occurrence of many missed cases. Between 1904 and 1916 only 144 further cases (six deaths) occurred in the United Kingdom, dwindling to two cases in the last three years.¹⁹¹ National smallpox control was effectively achieved in the succeeding decade. In England and Wales between 1935 and 1952 smallpox was imported on thirty-one occasions, spreading to the population twenty-five times.¹⁹² Maritime transmission to Liverpool occurred sporadically after 1903 and the last recorded smallpox case at the New Ferry Sanitary Hospital was a child disembarked from the *SS Cilicia* in April 1950, a P & O steamer mostly engaged in the India run.¹⁹³ In Europe between 1950 and 1971 acquisition of *Variola minor* from infected ship crews or officials occurred in five per cent of all reported cases (31/652) during that period.¹⁹⁴ The danger of introduction of ship-borne smallpox into the United Kingdom was emphasised by McGregor in 1942 who still stressed everything should be done to protect passengers and crew, and so minimize the risk to Britain.¹⁹⁵ Yet in the twentieth-century a valid vaccination certificate was not required for travellers to the UK by sea from India, Pakistan, Burma, or Nigeria, or countries important as virus reservoirs. The emphasis switched to diagnosis by ships' doctors and immediate vaccination of contacts on board became the normal procedure. It was hoped that late vaccination would protect contacts, identify them as exposed, and allow arising cases of smallpox to be quickly recognised.¹⁹⁶ Marsden emphasised quarantine of ships, as practised in other countries, following incidents on the *SS Tuscania* in Glasgow in 1929, and *SS Cathay* in the Port of London in 1938.¹⁹⁷ Dixon illustrated this with the example of the *SS Mooltan*, when contacts were quarantined for only four to five days and were then allowed free travel, leading to an outbreak which required an immense public health control effort.¹⁹⁸ Longer ship quarantine periods would have greatly reduced this risk to the local population, but was not required by law. In almost the last outbreak in the UK in 1962, an initial haematological diagnosis of *P. vivax* malaria in a child whose subsequent death was attributed to staphylococcal septicaemia, was later realised to be smallpox.¹⁹⁹ The pathologist, who completed the post-mortem, was unvaccinated and subsequently died of confluent smallpox. In the United States *Variola minor* became the dominant form. In 1906, so far as can be learned from the United States Public Health

191. McVail, *op.cit.* (note 49), 24.

192. Dixon, *op.cit.* (note 67), 314.

193. Port Sanitary Hospital, City of Liverpool Smallpox Register, *op.cit.* (note 30).

194. Thomas M Mack. Smallpox in Europe, 1950-1971. *The Journal of Infectious Disease*, 125, (1972), 161-169.

195. Alexander S.M. Macgregor, *Report of the Public Health Department*, (Glasgow, 1942).

196. Dixon, *op.cit.* (note 67), 341.

197. J. Pickford Marsden, Ship-borne smallpox, *BMJ*, 2 (1942), 706.

198. Dixon, *op.cit.* (note 67), 342.

199. Derrick Tovey. The Bradford smallpox outbreak in 1962: a personal account. *Journal of the Royal Society of Medicine*, 97 (2004), 244-247.

Department's records, severe smallpox cases were scarce, occurring in only nine of 12,503 reported cases.²⁰⁰ During the 1920s nearly 400,000 cases were reported with very low case fatality, and during the next decade few American states mandated vaccination and in 1971 routine childhood vaccination was discontinued.²⁰¹

Conclusions

Smallpox was regularly transmitted across the Atlantic after its arrival from tropical Africa in the fifteenth century.²⁰² Many other diseases failed to make the transfer for lack of suitable vectors.²⁰³ With the advent of rapid transatlantic steamers after 1860 American-United Kingdom transmission was guaranteed. Common factors across the cities of Boston and Liverpool, and late recognition of new infections in persons incubating the disease facilitated the occurrence of large epidemics of smallpox in these two cities. Transatlantic passage of infection corresponded temporally with the period of peak national incidence in the United States. This high infection risk was most likely channelled by maritime passage to Liverpool in 1901. Despite communications in 1901 between staff at the Liverpool Port Authority and the United States Public Health Service, there is no record of heightened maritime surveillance in either city or country.

Dr Edward William Hope, the Liverpool Medical Officer of Health during the epidemic, was essentially the counterpart of Dr Samuel Holmes Durgin, Head of the Public Health Department in Boston, who was considered one of the greatest public health physicians in nineteenth century America.²⁰⁴ Both steered development of effective control measures, through surveillance and screening, isolation, quarantine, contact tracing and selective vaccination around cases, now known as ring vaccination. Both contended with anti-vaccinationists which were especially vehement in Boston. The public health principles they implemented were later used by the global smallpox eradication programme.²⁰⁵ Post exposure smallpox vaccination can be critical in limiting transmission, and historical analysis of the Liverpool data suggests long-lasting protective effects of smallpox vaccination.²⁰⁶ This approach, adopted in Liverpool by the Port Authority with maritime cases, helps explain the city's success in its early control of the epidemic and the very rapid fall in incidence in 1903. Dr Hope's work established Liverpool as an international public health authority,

200. Chapin, *op.cit.* (note 3), 190.

201. Willrich, *op.cit.* (note 39), 338-339.

202. Guerra F. The European-American exchange. *History and Philosophy of the Life Sciences*, 15, 3 (1993), 313-327.

203. P. D. Curtin. Disease exchange across the tropical Atlantic. *History and Philosophy of the Life Sciences*, 15, 3 (1993), 329-356.

204. George A Babbitt. Retirement of Dr Samuel H. Durgin from the Boston Health Board. *American Journal of Public Health (New York)*. 2, 5 (1912), 384-5.

205. Henderson, *op.cit.* (note 135).

206. M. S, Keckler, M. G. Reynolds, I. K. Damon, K. L. Karem. The effects of post-exposure smallpox vaccination on clinical disease presentation: addressing the data gaps between historical epidemiology and modern surrogate model data. *Vaccine*, 31 (2013), 5192-5201.

pre-dating the wider global effort to eradicate smallpox.²⁰⁷ This contrasts with the much more gradual fall in incidence in Boston over several months where vaccine coverage and efficacy was much lower. Later probable transmission beyond Liverpool led to wide urban dispersion in northern cities and towns between 1902 and 1904. After 1905 control activities in the United Kingdom effectively reduced cases to minimal numbers²⁰⁸, whereas in the United States epidemics continued up until the late 1920s, when the country had the highest number of cases of any in the world except for India.²⁰⁹ The United States was the least vaccinated country for smallpox of any in the world.²¹⁰

The maritime origins of infection transported by record-breaking transatlantic liners of that time reflects the influence of commercial shipping interests requiring rapid turn-around times. The reluctance to implement strict quarantine, perhaps especially in Boston, was partly dictated by cost and commercial considerations. There is much to suggest that the Liverpool smallpox epidemic originated in Boston, but this is perhaps less important than other conclusions. The inter-change is a reminder of the greatly magnified risks with modern air transport of unrecognised infections combined with a high priority for commercial efficiency. This historical event is an unusual example of special ties forged between the United States and the United Kingdom through disease transmission rather than diplomacy.

207. Edward William Hope, *Health at the Gateway: problems and international obligations of a seaport city* (Cambridge: Cambridge University Press, 1931). Biographical details in: June Clayton, *Aspects of the life and work of Dr. Edward William Hope, Assistant Medical Officer of Health for Liverpool, 1883-94, and Medical Officer of Health for Liverpool, 1894-1924*. (Unpublished MPhil thesis: University of Liverpool, 1999). www.evolve360.co.uk/Data/10/Docs/13/13Clayton.pdf.

208. McVail, *op.cit.* (note 49). 24.

209. Hopkins, *op.cit.* (note 2), 291.

210. Chapin, *op.cit.* (note 3), 194.

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**Table I Number of maritime cases of smallpox landed from vessels in Port of Liverpool 1900
1904 in relation to United States origin and case fatality**

Sources: *Annual Reports on the Health of the City of Liverpool during 1900 to 1904*; Liverpool Smallpox Register, Wirral Archives, [reference notes 30, 93]

Year	Cases from ships arriving from Boston n (%)^a	Cases from ships arriving from other locations n (%)	Annual case total^b n (%)	Annual case fatality n (%)
1900	1 (3.7) ^c	26 ^d	156	23 (14.7)
1901	5 (21.7) ^e	18	37	6 (16.2)
1902	20 (44.4) ^f	25	560	20 (3.6)
1903	4 (16.6) ^g	20	1720	141 (8.2)
1904	4 (66.6) ^h	2	27	2 (7.4)
Total	34 (27.2)	91	2500	192 (7.7)

a Percentage of Boston and East coast United States transits of all Liverpool maritime cases for that year

b Annual number of cases for the city of Liverpool

c Single case landed at Queenstown, Ireland

d Includes nineteen cases on ship from Boston via the Mediterranean; one case on ship from New York

e Transported on two different ships

f Transported on seven different ships

g Four cases from New York. Sixteen different ships brought cases, or suspected cases, of smallpox

h Four cases from Baltimore

Table II United Kingdom smallpox period incidence and case fatality 1900-1905Sources: McVail, Table II, 6 [note 49]; Martin, Table II, 19 [*Journal of Hygiene*, 34,1(1934)]; UK Census, 1901 [note 39]

Location	Period in years ^a	Cases	1901 Census population	Period incidence per 10 ⁵	Deaths	Case fatality (%)
Lancashire & North-West England						
Liverpool	1901-03	2280	684958	333	160	7.0
Stockport	1902-04	159	78897	201	15	9.4
Oldham	1902-03	413	137246	301	32	7.7
Chadderton	1902-05	144	24000	600	5	3.5
Wigan	1902-03	70	60764	115	1	1.4
Blackburn	1902-03	141	127626	110	5	3.5
Salford	1902-04	262	220957	119	12	4.6
Manchester	1902-04	563	543872	103	33	5.9
Warrington	1903	86	64242	134	4	4.7
Macclesfield	1903-04	69	37500	184	5	7.2
Preston	1904-05	172	112989	152	8	4.7
Bradford	1901	28	279767	10	0	0.0
St Helens	1902-05	66	84410	78	3	4.5
ALL	1901-05	4453	2457228	181	283	6.3
Yorkshire & Pennines						
Ossett Union	1902-03	519	12903	4022	61	11.8
Heckmondwike	1904	91	9500	958	5	5.5
Dewsbury	1904	552	28060	1967	57	10.3
Leeds	1902-05	690	428968	161	35	5.1
Halifax	1903	141	104936	134	6	4.3
York	1902-04	39	77914	50	7	17.9
Batley	1904	103	128712	80	6	5.8
ALL	1902-05	2135	790993	270	172	8.0
Central England						
Leicester	1902-04	731	211579	345	30	4.1
Derby	1903-04	255	105912	241	5	2.0
Nottingham	1903-05	479	239743	200	17	3.5
Sheffield	1902-04	141	380793	37	5	3.5
Northampton	1902-03	44	87021	51	9	20.5
Birmingham	1902-05	364	522204	70	17	4.7
ALL	1902-05	2014	1547252	130	83	4.1
North-East England						
Tynemouth	1902-05	328	51366	639	17	5.2
South Shields	1902-05	272	97263	280	14	5.1
Chester-le-Street	1903-04	106	34000	312	6	5.7
Newcastle	1903-05	628	215328	294	28	4.5
Durham	1902	35	419782	8	1	2.9
Sunderland	1902-03	66	146077	45	4	6.1
Hull	1903-04	141	240259	77	8	5.4
ALL	1902-05	1576	1204075	131	78	4.9
South Wales and South-West England						
Swansea	1902	187	94537	198	187	17.1
Cardiff	1901-05	96	164333	58	5	5.2
Portsmouth	1902-05	20	188133	11	1	5.0
Bristol	1903-05	125	328945	38	1	3.2
ALL	1902-05	428	479948	89	39	9.1
London						
Greater London	1901-2	9484	6226494	152 (203) ^b	1540	16.2
Scotland and Ireland						

Glasgow	1900-04	3413 ^c	762000	448	371	10.9
Edinburgh	1900-04	191	303638	63	16	8.4
Dundee	1903-04	175	154734	113	12	6.9
Rest of Scotland	1900-04	2844	3251731	87	235	8.3
Dublin (hospital)	1903-04	243	448000	54	33	13.6

a: Annual periods may not include all months of the year dependent on month outbreak commenced or resolved.

b: Brackets is incidence estimate based on inner city London population alone.

c: Includes some cases from beyond city boundaries.

Table III Case fatality, smallpox vaccine efficacy and coverage during Liverpool, London, Glasgow and Boston epidemics between 1901 and 1903

City	Allegedly unvaccinated			Admittedly vaccinated			Total			Vaccine efficacy % (95% confidence interval) ^a	% cases vaccinated	% population protected (95% confidence interval) ^b
	Cases	Deaths	%	Cases	Deaths	%	Cases	Deaths	%			
Liverpool ^c												
Fazakerley Hospital	119	27	22.7	571	15	2.6	690	42	6.1	90.8 (82.1-95.3)	82.7	75.1 (67.9-78.8)
Park Hill Hospital	277	65	23.5	1063	35	3.3	1340	100	7.5	88.9 (82.8-92.8)	79.3	70.5 (65.7-73.6)
London ^d	194	98	50.5	760	108	14.2	954	206	21.6	83.8 (77.0-88.5)	79.7	57.1 (48.9-63.4)
Glasgow ^e	122	63	51.6	1642	150	9.1	1764	213	12.8	90.6 (86.1-93.6)	93.1	84.3 (80.2-87.1)
Boston ^f	842	188	22.3	754	82	10.9	1596	270	16.9	57.6 (43.8- 67.9)	47.2	27.2 (25.2-32.0)

^a Percentage reduction in case fatality in the vaccinated compared to unvaccinated group. Estimated from: $\frac{\text{attack rate unvaccinated} - \text{attack rate vaccinated}}{\text{attack rate unvaccinated}} \times 100$. An alternative equivalent formulation of vaccine efficacy is $[1 - \text{relative risk}] \times 100$, where relative risk is risk of developing the disease (or case fatality in this table) for vaccinated compared to unvaccinated people.

^b Calculated from $[\text{vaccine efficacy} \times \text{percentage cases vaccinated}]$, on assumption percentage cases vaccinated is indicative of population vaccine coverage.

^c Source: Edward W. Hope. Annual Report on the Health of the City of Liverpool in 1903. C.Tinling and Co., Printing Contractors, Liverpool, 1904, p 35, p 39 [note 73].

^d Source: The Jenner Society. *The London Epidemic of Smallpox*. London, 1901, p. 1. Analysis of epidemic data for London for 1901.

^e Source: John C. McVail. Smallpox in Glasgow, 1900-1902. *British Medical Journal*, 1902:40-43. Total cases mostly excludes children under five years.

^f Source: M.R. Albert, K.G. Ostheimer, J.G. Breman. The last smallpox epidemic in Boston and the vaccination controversy, 1901 -1903. *New England Journal of Medicine*, 344, 5, (2001), 375-378, [note53].

Figure Legends

Figure 1 Liverpool Port Sanitary Hospital Commemorative plaque

Figure 2 United States smallpox incidence per 100,000 population per annum, 28th June 1901 -27th July 1902

Sources: National Population Census data of 1900, [note 47]; Annual Report of state smallpox notifications of the Surgeon General of the Public Health and Marine-Hospital Service for 1901 [note 48].

Figure 3 Neighbourhood smallpox transmission linked to imported maritime cases from Boston

Sources: Port Sanitary Hospital Archives [note 30]; Annual Report on Health of the City of Liverpool during 1902 [note 73].

Figure 4 Commercial Map showing the transatlantic trade connections of the Port of Liverpool in 1903.

Source: Appendix, City of Liverpool. Handbook compiled for the Congress of the Royal Institute of Public Health., edited by E.W.Hope (Liverpool, Lee and Nightingale, Printers, 1903). Map production Spottiswoode and Co., Ltd., Liverpool. Commercially developed: red British Empire; Grey: other countries. Detail of transatlantic section from a world map.

Figure 5 Periodicity of Boston and Liverpool epidemics and dates of transatlantic ship sailings

Sources: [reference notes, 43, 50, 53, 68, 69].

Figure 6 Periodicity of London and Liverpool smallpox epidemics between 1875 and 1905

Sources: [reference notes, 27, 63, 93].

Figure 7 United Kingdom spatial smallpox period incidence per 10⁵ population 1900 -1905

Sources: McVail, Table II, 6 [note 49]; United Kingdom National Census, 1901 [note 99].

Figure 8 Comparative smallpox incidence 1900 -1903 per 100,000 population for Liverpool, Glasgow, London, New York, and Boston

Sources: [reference notes 3, 53, 66, 93]; W. J. Martin, The epidemic curve of smallpox, *Journal of Hygiene (London)*, 34, 1 (1934), Table II, page19; United States National Census 1900 [note 47]; United Kingdom National Census 1901, [note 99]