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REVIEW

Pioneers in infection control: John Snow, Henry Whitehead, the Broad Street pump, and the beginnings of geographical epidemiology

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Summary John Snow was one of the founders of epidemiology. Already convinced of the value of pure water, he analysed the distribution of cholera cases in the 1848 epidemic in relation to the purity of the water supply in London. His hypothesis that cholera was spread by contaminated water was tested by the 'Broad Street' epidemic of 1854. Snow quickly traced the water used in the houses affected by cholera to the pump in Broad Street, and persuaded the parish council to remove the handle. The epidemic subsided. The council did not really believe Snow, so the curate, Henry Whitehead, set out to repeat Snow's work, albeit at a more leisurely pace as the epidemic had subsided. He located 700 deaths within a 250-yard radius and showed that use of water from the Broad Street pump was strongly correlated with death from cholera. This surprised him as he had drunk water from the pump himself during the outbreak. Thus 'geographical epidemiology' began, although it was some years before Snow's observations were generally accepted.

Introduction

Two undervalued 'pioneers in infection control' are linked by their investigations into cholera, namely John Snow and Henry Whitehead. Snow (1815–1858) has an international reputation exceeding that of Semmelweis, partly because of the breadth of his work. He was a pioneer of anaesthesia and is the subject of a recent biography from Michigan State University, from which this review has drawn extensively.[1] The John Snow Society is devoted to him (www.johsnowsociety.org).[2] This review has also drawn from the anthology, 'Snow on cholera',

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which summarizes his work.[2] Henry Whitehead (1825–1896) was quite different; he was the curate of St Luke's Church in Berwick Street, adjacent to Broad Street, London at the time of the 1854 cholera epidemic. A memorial to him was written by Canon H.D. Rawnsley of Keswick, perhaps better known as one of the founders of the National Trust in England.[3]

John Snow: youth

John Snow was born in York, the eldest of seven children in a working-class family. Until he was 12 years old, he lived in Michaelgate, a particularly unsanitary area near the river that was often contaminated with excreta as well as providing household water. His father's job improved enough to move to a more salubrious area, and provide the best possible education for all seven children. At the age of 14 years, John was apprenticed to an apothecary called Hardcastle who was a family friend in Newcastle. Apprenticeship lasted for five years and involved much drudgery, including sweeping the shop floor, delivering drugs etc. However, in 1832, the Newcastle Medical School was founded and Snow, by then a senior apprentice, could attend clinical presentations and 'walk the wards'.

When he was 17 years old, Snow read an essay by one of vegetarianism's founding fathers, a London lawyer called John Frank Newton. Newton felt that many human problems were created by consumption of animal products and fermented liquors.[4] A regimen of 'distilled water and vegetables' had cured his chronic gastric disorder. Snow became a firm believer in this approach. He developed an abiding interest in the use of pure water and was a strict teetotaller.

Cholera

The first epidemic of the 'Asiatic cholera' hit England in 1831. It was called 'Asiatic' to differentiate it from 'cholera morbis', which was thought to be due to excess bile (choler). The disease came by sea and the results were devastating. The village of Upwell near the port of Wisbech lost '60 persons of all ages and sexes'; they were buried in mass graves in the churchyard marked merely with the letter 'C'. A memorial in the church ends: 'Reader think on this — why hast thou been spared'. Later, cholera appeared in Newcastle. Hardcastle sent Snow to nearby Killingbeck where the miners were badly affected. This must have been a fearsome situation for a 17 year old. Snow noted that miners were different to other workers in that they had no toilets down the mine, and they had to take food and drink with them, which they ate with unwashed hands. In the introduction to 'Snow on cholera', the following was written: 'His exertions were crowned with great success. He also made various observations in relation to this disease, which proved to him of immense account in later years.'[2]

John Snow: London life

Snow finished his apprenticeship in 1833 and became an assistant apothecary. However, he soon realized that he needed a London degree and so he became a student at the Royal College of Surgeons and then the Westminster Hospital. Once qualified, he embarked on a somewhat precarious life as a general practitioner in Soho, London. Life was enriched by membership of the Westminster Medical and Surgical Society, with weekly meetings for discussion of current research. In 1846, he watched one of the first operations under ether anaesthesia to be performed in London (Lister, then a medical student, had seen an operation the previous day).[5] The measure of Snow's subsequent success was his role as anaesthetist for two of Queen Victoria's deliveries. He moved to Sackville Street, off Piccadilly. His research continued and he developed chloroform anaesthesia, but he never lost his interest in cholera.

Cholera re-appeared in London in 1848 and again in 1853. No one knew the cause, although it had clearly come from abroad. As late as 1853, an editorial in *The Lancet* said, 'what is cholera?…all is darkness and confusion, vague theory, vain speculation …'.[6] Two opposing theories were 'contagion' (contact with a sick person's body or fomites) and 'miasma' (some vague atmospheric presence). The 1848 epidemic convinced Snow that cholera was a disease of the bowel, and was spread by faecal-oral transmission. Rather like Semmelweis (also in 1848), he postulated spread by microscopic morbid matter or particles and stressed the value of handwashing. His subsequent actions became a model for epidemiologists. Firstly, anecdotal experiences pointed the way, then a major point-source outbreak served to prove his hypothesis, and finally a retrospective survey showed how it all fitted.

In the 1840s, the population of London obtained water either from their own wells or from piped supplies provided by commercial companies, which were fed into wells or tanks (butts) and

pumped as required. Sewage was disposed of on fields ('night soil'), collected in cesspits (sometimes connected to sewers), or passed into the River Thames either directly or through sewers. Writing in 1849, Snow noted that if 'miasma or contagion' were the causes of cholera, it 'would be confined to the dwellings of the poor…but there is a way open for it to extend itself more widely and reach the well to do. I allude to the mixture of cholera evacuations with the water used for drinking…'

The same year, two reports from Mr Grant, the Assistant Surveyor for the Commissioner of Sewers, reinforced Snow's ideas. The first related to Horsleydown, Bankside, in Southwark. As it was on the River Thames and as 'night soil' could no longer be spread on St George's Fields (they had been built on), much of the sewage went directly into the river, flushed by the newly arrived water supply obtained from the river. In 1845, 5% of Bankside's population died of cholera. Grant's first report was of a naturally controlled experiment in two adjacent blocks of houses (Surrey Court and Truscott's Buildings in Thomas Street). Between the blocks were privies and small cesspools, and beside them ran a polluted ditch. Both were served with wells fed with river water by the same company. Initially, people in both blocks developed cholera (presumably from the water). However, thereafter, only Surrey Court was affected; 11 deaths compared with one death in Truscott's Buildings. Grant found that the well in Surrey Court often overflowed and water returned to the well contaminated with debris. The other well remained (relatively) clean. Snow visited Southwark but noted 'the surviving inhabitants nearly all left the place immediately after the above mortality occurred so I could not complete my investigation'.

The other report concerned Albion Terrace in Lambeth (genteel suburban dwellings of professional and tradespeople), where one or two cases occurred initially. However, an outbreak followed a heavy rainstorm, which presumably washed faecal matter into a drinking water tank. All the tanks on Albion Terrace intercommunicated. When Grant went to investigate, he found that one tank contained '6—9'' of deposit… which possessed the odour of privy soil', some of which he sent to Snow who found various substances which had passed through the alimentary canal, such as stones and husks of currants and grapes. Altogether 20 died and 'four or five were attacked after flying from the place'.[3]

These two incidents led Snow to hypothesize that river water contaminated by cholera evacuations explained variations in mortality throughout London. He examined the weekly returns of births and deaths during the 1848 epidemic. William Farr, the Compiler of Abstracts for the General Registry Office, had gathered the data. South of the Thames, where water supplies came from the lower reaches of the river, mortality was 10 times higher than that to the north of the Thames, where clean water was used. This was not real proof, but was certainly a pointer. At least, he ruled miasma out, as the smells in Central London were no different from those south of the Thames. He published a pamphlet on 'The mode of communication of cholera'. A later paper noted that the pathology was confined to the gut, which had been poisoned by 'particulate matter' from faeces.[2]

Henry Whitehead

Henry Whitehead (Figure 1) had a middle-class background. His father was headmaster of

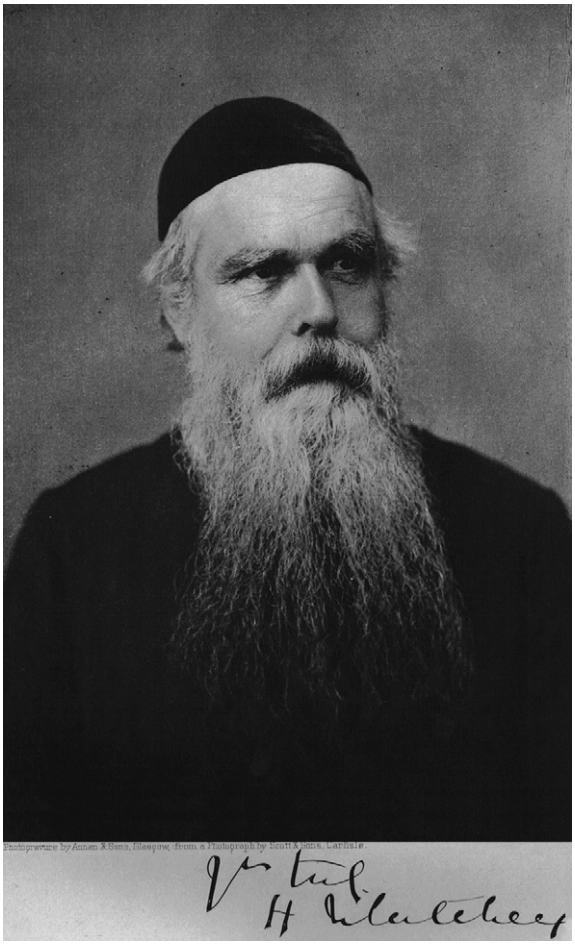

Figure 1 Henry Whitehead.

Chatham House School, which still exists in Ramsgate. Henry therefore grew up in academic surroundings and became very good at collecting data and writing. His parents both imparted a sense of caring. 'The religious atmosphere in which he grew up however….included Sunday observances (so strict)… that it was a wonder the boy ever entered the ministry'.[3] After some years teaching at Chatham House, he entered Lincoln College, Oxford. Here, his innate sense of humour emerged and he produced poetry and made music. He came to know 'a great deal more about men than he had ever hoped'.

When Whitehead came down from Oxford determined to become a parish priest, 'the demand for curates was less than the supply, and jobs were not as plentiful as blackberries'. However, in 1851, he became attached to St Luke's Church, which had just been built in Berwick Street, Soho. This church had a very brief life; it was consecrated in 1839 and demolished in 1936. In the 1850s, the whole area was very run down despite its proximity to upper-class Mayfair. Many buildings were 'wretched hovels — a disgrace to humanity', and parishioners were put off attending church because of the 'low and turbulent population' that frequently interrupted the services. Even today, the small shops and street market of Berwick Street contrast with the large stores of Regent Street, which runs parallel and to the west of it. Running at right angles between the two roads was Broad Street. Whitehead rose to the challenge and 'lived the life of human friendship in the world of friendlessness'.[3]

Broad Street and the cholera epidemic

Broad Street is no longer to be found on the London map as it became Broadwick Street in the 1930s. Large terraced houses (some of which remain) were originally built there for upper-middle-class families, but they were used as tenements by the 1850s, with up to 50 people in one house. Those on the upper floors were occasionally seen to haul a cow up to supply milk. Gullies in front of the houses communicated with an open sewer. Many houses had cesspits for sewage, although during the epidemic, cholera-laden evacuations were discarded through the windows into the back gardens. Water was supplied to a well and pumped up as required. Figure 2 shows the south side of Broad Street. The large building was the Lion Brewery and the street also housed the Eley cartridge factory. Just to the north was a large site occupied by a workhouse (a refuge for the poor), and St Luke's Church was one block behind the left edge of the picture.

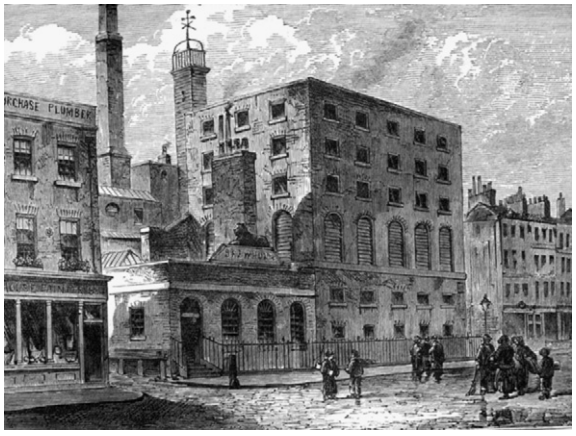

Figure 2 The south side of Broad Street in the 1800s (note the pump).

On Monday 24 August 1854, Mrs Lewis of 40 Broad Street washed her baby daughter's nappies in water, which she subsequently emptied into the cesspool in front of the house. A few feet away, people gathered around the water pump; the water was held in such high esteem that people came from neighbouring streets for it. The Eley brothers sent a daily flagon to their mother in Hampstead, and honoured their parent's wishes by keeping two barrels of fresh water in the factory. No one realized that the baby had cholera. By the time she died on Saturday, 'The angel of death had spread his wings over the place'. Whitehead later found that 700 deaths occurred within a 250-yard radius.

Cholera spared Hampstead except for Susannah Eley, who died on Saturday, by which time several of the Eley factory workers were ailing and later died. On Sunday, Snow, who lived only 10 minutes walk away, heard of the epidemic. As he knew that the North London water sources were unpolluted, he suspected a contaminated water pump. He obtained samples of water from several pumps in the area. The Broad Street water looked the cleanest. However, microscopic examination revealed 'a good deal of organic matter' and some 'oval animalcules'.

On Tuesday, Snow obtained the names and addresses listed on 83 death certificates from the Registry Office. He visited the relevant houses enquiring what water was drunk. He went to the surrounding areas and found that most of those affected had fetched their water from the Broad Street pump. On Thursday, he attended the 'outbreak meeting' of the local parish's 'Board of

Governors and Directors of the Poor' and asked that the pump handle be removed. Although the Board members favoured 'miasma', they nonetheless took Snow's advice. This was unpopular with the inhabitants who preferred the Broad Street water to their filthy water tanks. However, the epidemic subsided.

Snow later found that the numbers of deaths were greater than he originally thought. He produced a map relating cases to the Broad Street pump and showing that, in general, people who used other pumps were unaffected (Figure 3). Two pieces of 'negative data' supported his case. In contrast to the Eley factory, there were no cases in the Lion Brewery (workers drank the beer) or in the workhouse (which had its own well).

Although the Board of Governors did not really believe the pump story, they had it opened up and the brick shaft examined. It seemed perfectly in order. The expense of an inquiry discouraged them from further action, but their consciences were assuaged when Henry Whitehead told them that he could easily disprove Snow's theory. He began a survey lasting for three months in February 1855, by which time the disease had died down and he was able to take his time. The 'miasma' theory was disproved by one observation that in an adjacent street (Peter Street), there was a cut-off point half way down. The house nearest the Broad Street pump had 11 deaths from cholera, while the house beyond (whose inhabitants used a different pump) only had one. Was 'fear a problem'? 'When pestilence slays its thousands, fear slays tens of thousands' wrote Whitehead. However, the workhouse was unaffected although the inmates had the most to fear. The 'dead house' (mortuary) received 80 bodies. Cleanliness was seemingly irrelevant, since three houses previously known to be the cleanest in the area lost 12 inhabitants while the filthiest house lost none.

Far from damning Snow's hypothesis, Whitehead's survey confirmed it. Of those who drank pump water, 58% developed cholera compared with only 7% of those who did not. He also found that the deaths related to people drinking the water in the first part of the period between the nappy washing and removal of the pump handle. He himself had used pump water to dilute his brandy late during that dreadful week. This suggested that a 'pulse' of contamination had entered the pump shaft and been gradually diluted out.

Another engineering survey was commissioned. This revealed that the cesspool drain was partially blocked, and the earth between it and the pump shaft, which was only 2′ 8″ away, was wet. The surveyors concluded that there had been a consistent leak from the cesspool to the pump shaft. Thus, Snow's observations were fully substantiated. In September 1855, the pump handle was finally replaced at the request of the inhabitants who still felt that the quality of the water was much better than that in their own water tanks.

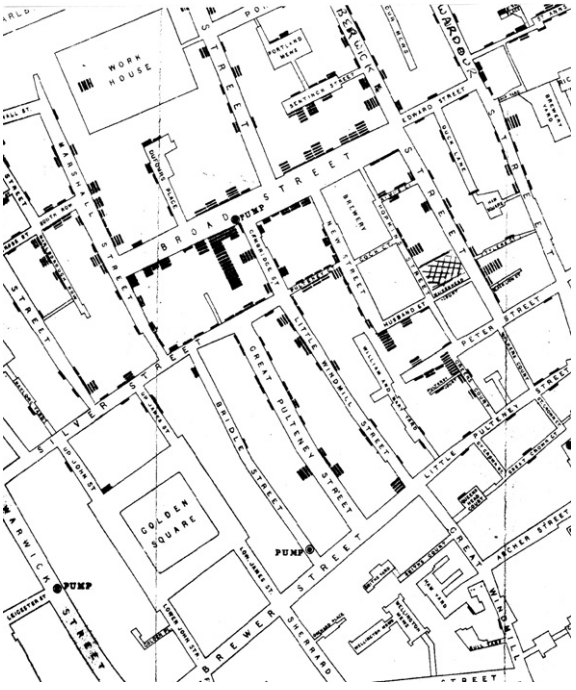

Figure 3 Part of Snow's map. The cross-hatch indicates St Luke's Church. Black lines indicate deaths.

London's water supplies and cholera

Snow, meanwhile, continued to study death rates in relation to water supply using addresses of those who had died of cholera obtained from the Registrar-General's office. He concentrated on areas supplied by water from the River Thames, which was becoming steadily more polluted. Districts served by two companies (Lambeth Water Company and Southwark and Vauxhall Water Company) had had equal numbers of cholera deaths in 1849. Both supplied water to the populations south of the Thames, sometimes to adjoining parishes. However, from 1852, Lambeth Water Company moved its water intake upriver to Thames Ditton from Hungerford.

'The two companies were in active competition. In many cases, a single house has a supply different

to those on either side… The experiment too was on the grandest scale. No fewer than three hundred thousand people of both sexes, every age and occupation, and of every rank and station were involved….and without their knowledge one group being supplied with water containing the sewage of London.' Mortality in houses supplied by Southwark and Vauxhall Water Company was eight to nine times greater than in houses supplied by Lambeth Water Company. Snow's table shows the outcome during the 1854 epidemic (Table I). Snow published these results in the second edition of his book in 1855.[2]

Conclusion

Snow only lived for another three years; in June 1858, just as he had written the word 'exit' in a book on anaesthesia, he had a fatal stroke. Sadly, it was some time before his work was taken seriously — he had never been considered one of the 'medical elite'. *The Lancet* noted his death on 28 June 1858, with just two lines on his role as an anaesthetist. William Farr, rightly considered as one of the founders of epidemiology, had analysed the same data on the 1849 cholera deaths in 1852 and concluded that height above sea level was the main factor. He even showed that the data supported 'miasma' (atmospheric vapours).[7] The report of the Scientific Committee deputed to investigate the Broad Street epidemic in 1855 stated, 'On the whole evidence it seems impossible to doubt that the influences, which determine in mass the geographical distribution of cholera in London, belong less to the water than the air…'.[8] The 1858 volume of *The Lancet* is filled with comments on the state of the River Thames — 'black ink smelling of sulphuretted hydrogen', and of the 'serpentine' lake — 'pea soup'. Nonetheless, London's first 'medical officer of health,' Sir John Simon, took some decades to be convinced of Snow's hypothesis.

Whitehead, however, regarded Snow 'as great a benefactor to the human race as has appeared in the present century'. He quoted a letter published in *The Lancet* stating 'I believe that since the days of Jenner no physician has given greater service to mankind'.[9] In the 1860s, he published two articles in *Macmillan's Magazine* on 'The influence of impure water on the spread of cholera'[10] and on 'The Broad Street pump: an episode in the cholera epidemic of 1854'.[11] He himself was credited as 'fighting like a hero night and day with hands and lips and brain, helping to strengthen the living, heal the sick, and comfort the dying' during the epidemic.

Interestingly enough, Robert Koch, aided by his ability to grow the cholera-causing vibrios, came to similar conclusions during a study of cholera in Germany in 1892.[12] Like Snow, he studied point-source outbreaks and used mapping to show relationships to water supply. He also showed that the town of Altona, although downstream of Hamburg, was protected by the filtration of its water through sand. There is no evidence that he knew of Snow's work, but he quoted Farr (by then converted to Snow's thesis) who ascribed infections in 1866 to water from East London waterworks (although he still believed that air was the reason for the spread of sporadic cases).[13] At that time, the efficacy of filtration could not be demonstrated bacteriologically, but Koch felt that the presence of eels in domestic water tanks flagged a failure.

The breadth of Snow's work has made him one of the most revered scientists of his age. He pioneered 'geographical' epidemiology. The UCLA has devoted a website to his life and work. Broadwick Street contains the 'John Snow' inn with a first floor display devoted to his work (something his teetotal self might have disapproved of), a replica of the famous pump and his picture on the inn's sign (Figure 4).

Snow's work raised several questions that have now been answered. Firstly, the Broad Street baby was a prototype. Breast-fed babies can be a good source of bacteria, often without being ill.[14] Secondly, he showed that 60% of people who used the Broad Street pump became infected. What of

Table I Snow's analysis of the 1854 epidemic

	Number of houses	Deaths from cholera	Deaths per 10 000 houses
Southwark and Vauxhall Water Company	40 046	1263	315
Lambeth Water Company	26 107	98	37
Rest of London	256 423	1422	59

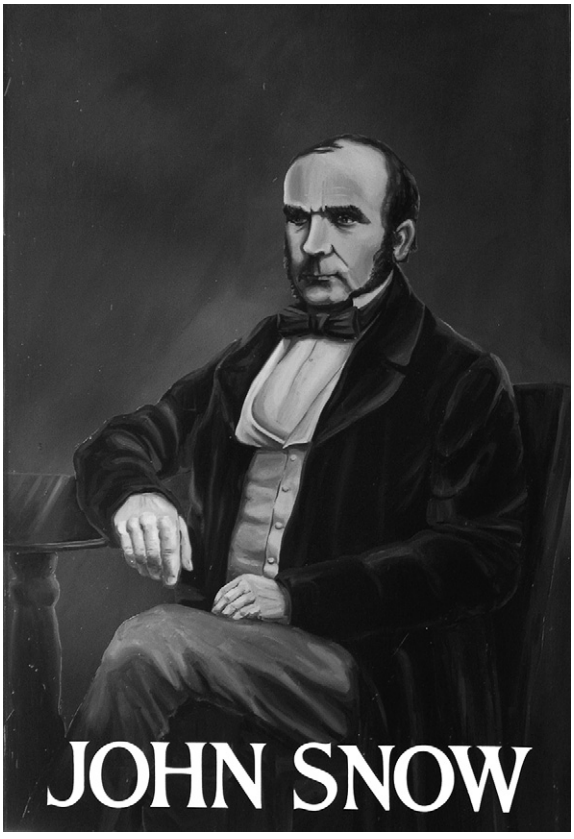

Figure 4 The 'John Snow' inn sign.

the others who did not? Why was the famous hygienist Pettenkofer, who disbelieved both Snow and Koch, able to drink a cholera culture (albeit of a strain of low virulence)?[15] The vibrio bacillus flourishes in an alkaline medium. Recent work has shown that infection with *Helicobacter pylori*, which causes hypochlorhydria, increases the risk of acquiring severe cholera.[16]

The last word comes from a recent paper in *Public Health* that vindicates Snow.[17] The authors reworked Farr's data using logistic regression (a technique not available at the time) and showed that rather than the height above sea level, water supply was, in fact, the most important risk factor.[8]

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