Public Health Then and Now

A Rivalry of Foulness: Official and Unofficial Investigations of the London Cholera Epidemic of 1854

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ABSTRACT

Contemporaneous with John Snow's famous study of the 1854 London cholera epidemic were 2 other investigations: a local study of the Broad Street outbreak and an investigation of the entire epidemic, undertaken by England's General Board of Health. More than a quarter-century prior to Koch's description of *Vibrio comma*, a Board of Health investigator saw microscopic "vibriones" in the rice-water stools of cholera patients that, in his later life, he concluded had been cholera bacilli. Although this finding was potential evidence for Snow's view that cholera was due to a contagious and probably live agent transmitted in the water supply, the Board of Health rejected Snow's conclusions.

The Board of Health amassed a huge amount of information which it interpreted as supportive of its conclusion that the epidemic was attributable not so much to water as to air. Snow, by contrast, systematically tested his hypothesis that cholera was waterborne by exploring evidence that at first glance ran contrary to his expectations. Snow's success provides support for using a hypothetico-deductive approach in epidemiology, based on tightly focused hypotheses strongly grounded in pathophysiology. (*Am J Public Health*.1998;88:1545–1553)

> Either in air or water it seems probable that the infection can grow. Often it is not easy to say which of these media may have been the chief scene of poisonous fermentation; for the impurity of one commonly implies the impurity of both; and in considerable parts of the metropolis (where the cholera has severely raged) there is rivalry of foulness between the two.
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> *Report of the Committee on Scientific Inquiries in Relation to the Cholera-Epidemic of 1854*[6]

John Snow's investigations of the London cholera epidemic of 1854,[1] particularly the Golden Square outbreak in the first days of September 1854—which he linked to the water of the Broad Street pump—are so much a part of the epidemiologic tradition that they have overshadowed 2 contemporaneous investigations of that epidemic, both undertaken by government authorities. First, the vestry of the Parish of St. James, Westminster, studied the Golden Square outbreak that took place in its parish.[2] The vestry's investigative arm, the Cholera Inquiry Committee, came to conclusions that bolstered Snow's view of the pump as the likely source of the epidemic. It uncovered the probable index case, a 5-month-old baby (not enumerated by Snow), and reexamined the Broad Street pump, which Snow had considered physically intact. It also discovered a decayed foundation in close proximity to the cesspool of the house of the index case. Although the Cholera Inquiry Committee report is reasonably well known,[3–5] a second study, a study of the entire London epidemic by England's General Board of Health, has less often been described.

The Board of Health investigation was extensive, producing 4 reports totaling 308 pages and a 352-page scientific appendix with 98 tables, 8 figures, and 32 colored plates.[6] The Board's investigations included quantitative analyses of the relationship of cholera incidence to air and water temperature, rainfall, barometric pressure, humidity, wind pressure and direction, ozone level, cloud cover, crowding, and altitude. Microscopic and chemical analyses were performed of air in cholera wards, of water samples from all water companies and from many sites (including the Broad Street pump), and of sewage and fecal samples. The historian Margaret Pelling has claimed that this investigation was the first occasion in 19th century England in which a health department of government had promoted and financed scientific research.[7] But the Board of Health came to conclusions very different from those of either Snow or the Cholera Inquiry Committee.[8]

These 3 investigations were conducted almost simultaneously and with some collaboration. Snow, for example, was a member of the Cholera Inquiry Committee. A Board of Health inspector provided 2 key pieces of evidence that Snow used to support his hypothesis. It was at Snow's request that the Board of Health included Broad Street pump water among its examined water samples. All 3 investigations made use of epidemic spot maps of cholera deaths, and the most complete and detailed map of cholera in the Golden Square neighborhood was not Snow's but one published both by the

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Board of Health and by the Cholera Inquiry Committee.

In this paper we focus on the Board of Health investigation and the political environment that may have shaped its conclusions. We compare its scientific approach and mode of operation with that of John Snow, and we weigh the implications of these different approaches for contemporary epidemiology.

The General Board of Health

In 1848, Parliament passed the Public Health Act, which instituted a General Board of Health for a 5-year period with limited powers: to sanction expenditures for sanitary improvements requested by local governments and to provide guidance and regulations in the event of an epidemic. The Board originally consisted of 3 lay members, one of whom was Edwin Chadwick, whose 1842 *General Report on the Sanitary Condition of the Labouring Population of Great Britain* is referred to by the historian George Rosen as "the fundamental document of modern public health."[9] In 1850, the Board added a physician, Thomas Southwood Smith, whose 1838 Poor Law Report supplement, *On Some of the Physical Causes of Sickness and Mortality to which the Poor are Particularly Exposed, and which are Capable of Removal by Sanitary Regulations*, had established his sanitary credentials.

The creation of a Board of Health was a high point of the great Victorian enterprise of sanitary reform, whose central idea was that environmental circumstances—particularly pollution of air and water, defective sanitation, dampness, filth, and overcrowding—were causes of disease, particularly epidemic disease, and that these diseases often killed the wage earners, left poor working families impoverished, pushed widows and orphans into workhouses, and undermined the moral fiber of the working classes. Sanitary reformers argued that it was therefore in the economic self-interest of the nation to rid itself of these environmental circumstances by centralized public health action.

In spite of its limited powers, the Board of Health investigated many local sanitary deficiencies between 1848 and 1854 and issued several reports that aroused anxiety and irritation among business and medical interests. Chadwick in particular was viewed as arrogant and uncompromising. As a result, on July 31, 1854, Parliament refused to renew the Board and dismissed its members, thus abolishing the only central public health body in the country just as England's third cholera epidemic of the century was getting under way. The number of cholera deaths in London had increased from 1 per week to 133 per week during July.

The following day (August 1, 1854), Parliament created another Board of Health, but one that was decidedly weaker than its predecessor. It required annual reauthorization and was staffed by a single member, who was required to be a member of Parliament. By the time Sir Benjamin Hall, MP,[10] assumed the office of President of the General Board of Health on August 12, 1854, the number of weekly cholera deaths in London had increased to 644.

The Board of Health Cholera Investigation

The accelerating cholera epidemic dominated the activities of the new Board of Health. On his first day in office, Hall appointed sanitary inspectors to monitor the progress of the epidemic and to arrange preventive measures and medical relief for the sick. Learning of the outbreak in Golden Square shortly after it occurred, Hall sent a team of physicians to perform a house-to-house investigation of the Golden Square district on September 5.

The next day, Hall met for the first time with an advisory medical council that he had just assembled. This council consisted of some of the most eminent medical practitioners of the day, including John Ayrton Paris and James Alderson, president and treasurer, respectively, of the Royal College of Physicians; William Lawrence, vice-president of the Royal College of Surgeons; and John Bacot, master of the Society of Apothecaries. James Clark, physician ordinary to the Queen, and Neil Arnott, physician extraordinary to the Queen, were also members, as were Benjamin Babington, founder and president of the London Epidemiological Society, and 2 important public health officials—William Farr, the compiler of abstracts in the Registrar General's office, and John Simon, medical officer of health of the City of London. In effect, Hall had brought the leadership of organized medicine and public health into the first activities of the new Board of Health.

The Medical Council divided itself into 3 committees—the Committee for Scientific Inquiries (CSI), the Committee on Treatments, and the Committee for Foreign Correspondence.[11] The work of the first of these committees was the centerpiece of the report.

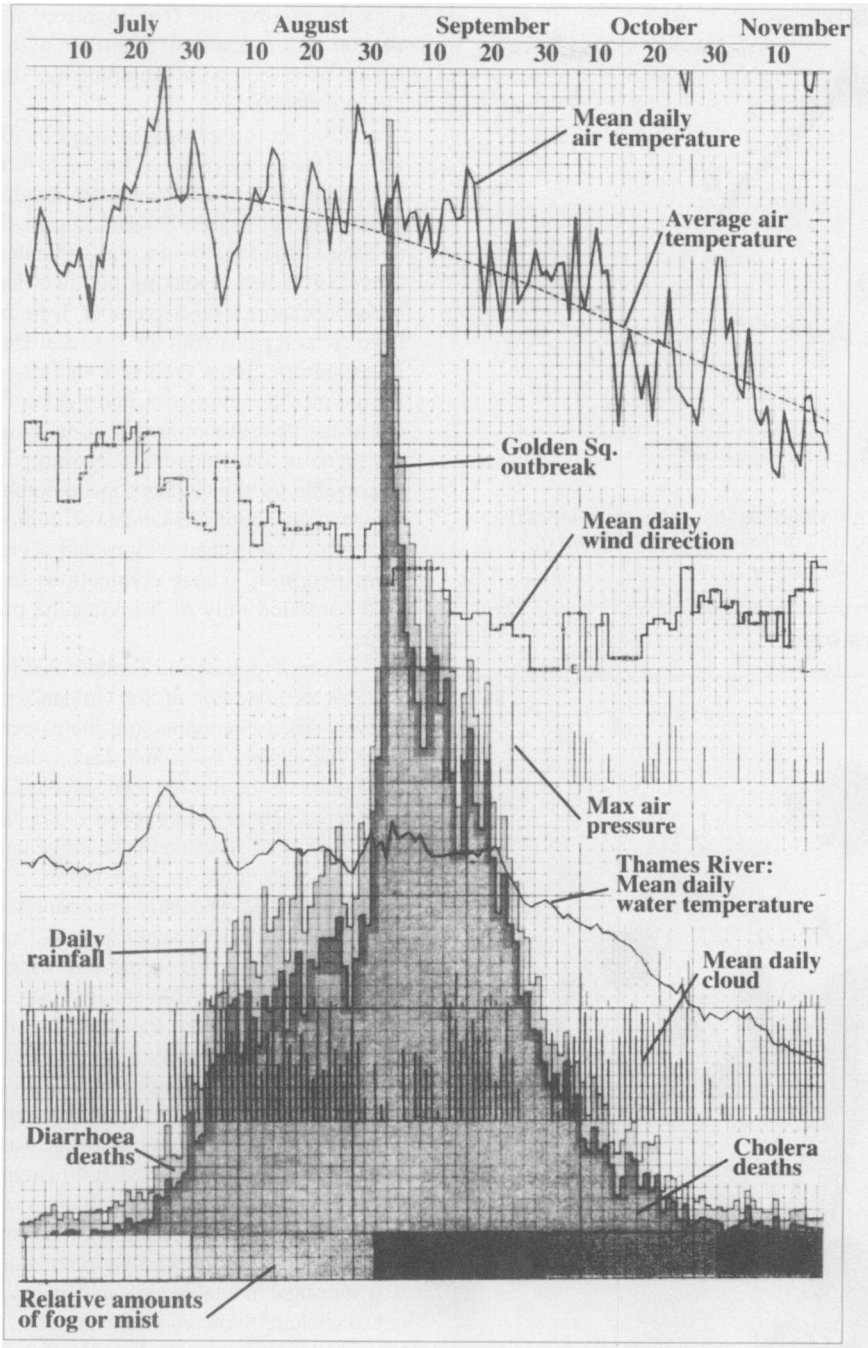
Five particularly eminent physicians, all with ties to the sanitary reform movement—Neil Arnott, William Baly, William Farr, Richard Owen, and John Simon—constituted the CSI.[12] Hall also appointed 3 scientists to undertake investigations for the CSI: James Glaisher, superintendent of the magnetic and meteorological department at Greenwich and a founder of the British Meteorological Society; Richard Dundas Thomson, professor of chemistry at St. Thomas' Hospital[13]; and Arthur Hill Hassall, author of the first textbook of microscopic anatomy in English (1846) and famed for his revelations, through microscopy, of the extraordinarily frequent contamination of food and water in London by adulterants and animalcules.[14]

Glaisher's investigations of meteorological conditions in London occupied almost a third of the 352-page scientific appendix that accompanied the report of the CSI.

Figure 1 shows part of Glaisher's plot of cholera deaths in London in 1854 in relation to atmospheric phenomena. In the original, cholera deaths were given in blue, diarrhea deaths in yellow. In our copy, the darker outline indicates cholera deaths. The sharp peak on August 31 to September 2 is the Golden Square outbreak, a point-source outbreak superimposed on a propagated epidemic. Also plotted on this figure are barometric pressure; daily highs, lows, and means in air temperature; wind pressure and direction; temperature of the Thames; rainfall; cloud cover; and fog. In addition to the measurements plotted here, daily atmospheric measurements of ozone level, humidity, vapor pressure, and dew point were also taken at 23 stations in London and its suburbs.

The CSI also undertook chemical and microscopical examinations of water and, to a lesser extent, air. Thomson, the chemist, and Hassall, the microscopist, both examined water samples from various water companies and from many different locations. Thomson produced a hierarchy of water quality based on the proportion of organic solids in the water, which rated water from the Lambeth Company highest and water from the Southwark and Vauxhall Company lowest (precisely paralleling Snow's correlations of the South London water supply with cholera mortality).

Examination of the air for microscopic organisms was ingeniously undertaken with the use of a 16-cu-ft zinc-lined wooden tank designed by Thomson, which suctioned large volumes of air from the wards of St. Thomas' Hospital through a distilled water trap.[15] The water was then examined microscopically. Among the several items seen, which included fungal mycelia and sporules, wool fibers, and hair, were minute organisms that Thomson referred to as *vibriones* (conventional 19th-century terminology for many motile, elongated microscopic organisms) (Figure 2).



Source. Appendix to Report of the CSI (opp p 106).[6]

FIGURE 1—Cholera deaths in 1854 plotted against atmospheric phenomena.

Thomson sampled air from a ward filled with cholera victims, a half-filled cholera ward, and an empty ward, but vibriones were seen only in the full cholera ward. Thomson, however, was conservative in his conclusions:

> [I]t would be premature to infer a connexion between the disease and these organisms until extensive comparative trials have been made on other conditions of air.[16]

Meanwhile, Hassall examined several sources of London water under the microscope. Southwark and Vauxhall water (Figure 3) contained a veritable zoo of creatures; by contrast, water from the Broad Street pump (Figure 4) was relatively bereft of microscopic animal life.

Hassall's hierarchy of water supplies was based on different criteria than Thomson's—the relative number of animalcules and microscopic organisms he found in each sample—but he drew the same conclusions. Hassall rated Lambeth water purest, Southwark and Vauxhall water among the most contaminated, just as had Snow and Thomson. Thomson had discovered vibriones in filtered air from a full cholera ward; Hassall saw vibriones in the rice-water stools of cholera victims (Figure 5):

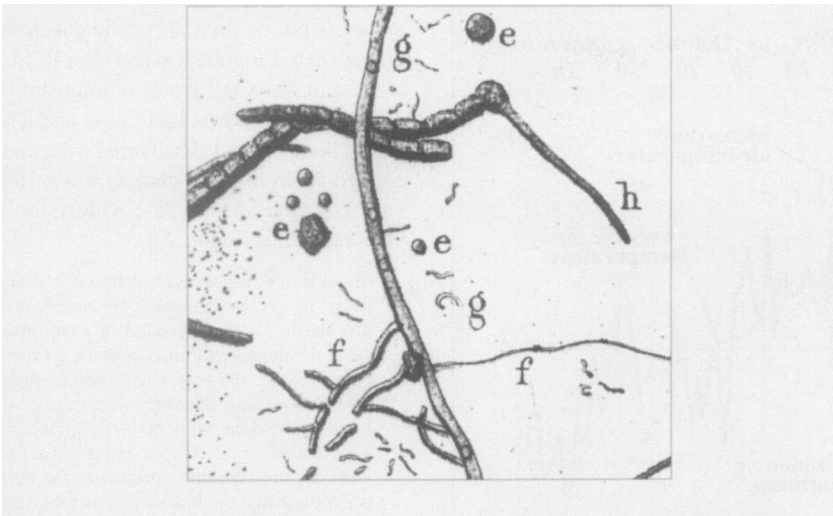
> Myriads of vibriones were detected in every drop of every sample of rice-water discharge. . . . I succeeded in examining several samples within two hours of their being voided, and two others from separate cases immediately after they were evacuated. In all of these the vibriones were present in large numbers. . . . It thus appears that the vibriones are constantly present in the rice-water discharge of cholera, and that they are developed in it during life, and while retained in the small intestines.[17]

Although he wrestled with the possibility, Hassall did not consider these vibriones the cause of cholera:

> [W]hat is the origin or source of these vibriones, and what (is) their relation to cholera? . . . there is no doubt but that there is more than one source for them. . . . It is possible that they may obtain entrance into the stomach and bowels by means of the atmosphere, and it is perfectly certain that they do frequently gain admission through some of the impure waters consumed, in which I have not unfrequently detected the presence of vibriones. . . . Once introduced into the alimentary canal, they are brought into relation with conditions highly favorable to their development and propagation. . . . I have made two or three examinations of healthy and natural faecal evacuations at the time of their being passed, and in these I have detected the presence of comparatively a very small number of vibriones. . . . That they should not be present, or if present, only in small numbers, in healthy intestinal evacuations, is satisfactorily explained by the fact that the circumstances favorable to their development do not exist in the same degree as in cholera.[18]

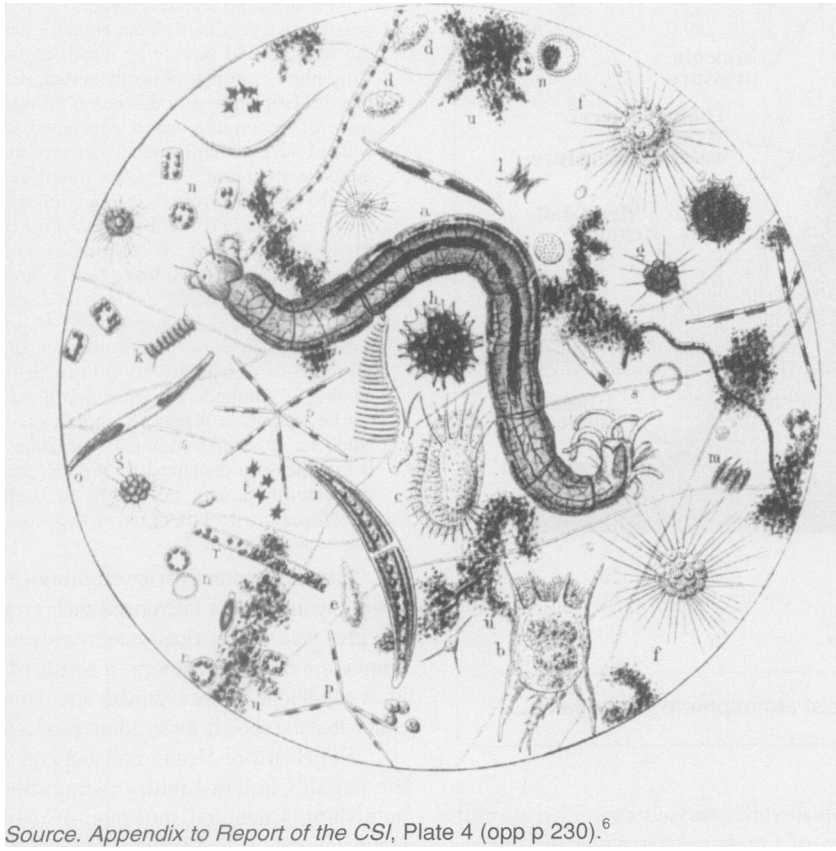
Hassall apparently viewed vibriones as living organisms but interpreted their swarming presence in the rice-water stools as an epiphenomenon of cholera, a result of the ideal conditions for their growth and multiplication that the cholera evacuations produced.[19]

The Board of Health collaborated with the parish Cholera Inquiry Committee in publishing a detailed spot map of cholera victims in the Golden Square district. Unlike Snow's better-known version, this map included all streets and mews, updated the number of cholera deaths in the area by tracing people who left the neighborhood for hospitalization, and tallied deaths of nonresidents who worked in or visited Golden Square. The Board of Health map also indicated the correct site of a burial pit used



Note. e = sporules, f = fungi in very early stage, g = vibriones, h = fungi in advanced stage. [Author comment: Note comma shape to one of the vibriones (labeled g).]
Source. Appendix to Report of the CSI, Plate 1 (opp p 122).[6]

FIGURE 2—Vibriones from the air of a cholera ward.



Source. Appendix to Report of the CSI, Plate 4 (opp p 230).[6]

FIGURE 3—Sample of water supplied by the Southwark and Vauxhall Company.

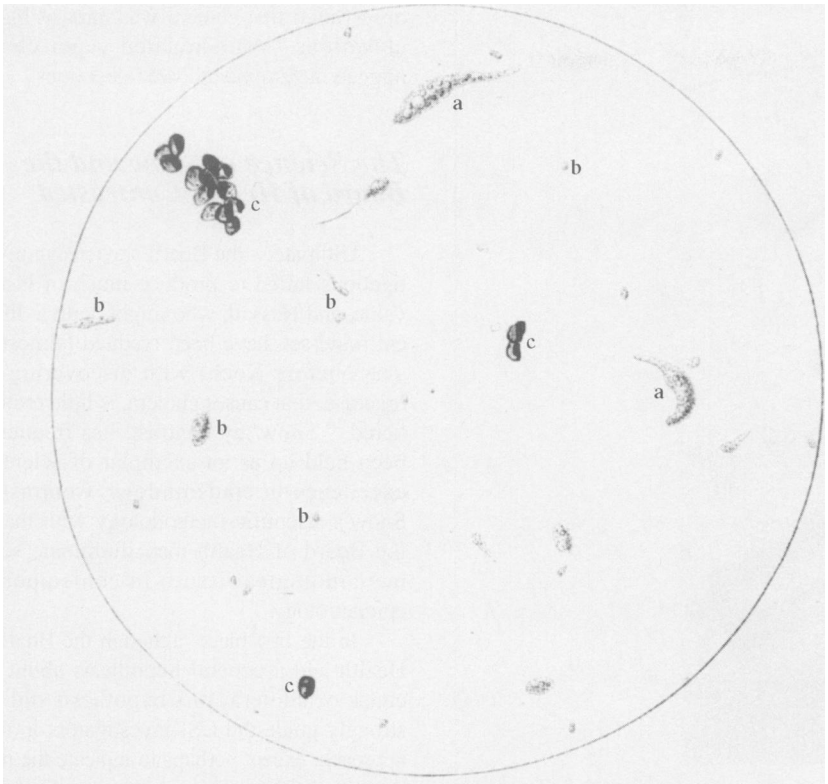
during the Great Plague of London in 1665. Many believed that the disturbance of the plague pit that allegedly occurred when sewer lines were dug in the 1840s was responsible for the severity of the Golden Square outbreak. But the jointly published map of the Board and the parish committee established that the true location of the plague pit corresponded neither with the sewer work nor with the epicenter of the cholera outbreak.

The team of physicians sent by Benjamin Hall to perform a house-to-house inspection of the Golden Square neighborhood were Drs Fraser, Hughes, and Ludlow, and they began their work on September 5. Since Snow began making his own neighborhood inquiries on September 3, he must have crossed paths with the Board of Health investigators. Snow credits a Dr Fraser as having provided him with information critical to his determination that contaminated water from the Broad Street pump was responsible for the Golden Square outbreak: information about the deaths of 2 cholera victims, a Hampstead widow and a visitor from Brighton, whose connections to the area consisted only of drinking the pump water.[20]

Fraser, Hughes, and Ludlow described in detail the condition of 800 Golden Square houses—their occupants and their occupations, the cholera cases and deaths, and the conditions of the houses themselves. Every uncovered cesspool, untrapped drain, filthy privy, sink, and slaughterhouse in the neighborhood was noted in their report. Their description of a particularly important house, at 40 Broad St, is shown in Figure 6. During its investigation in the spring following the epidemic, the parish Cholera Inquiry Committee discovered that the cesspool of 40 Broad St lay inches away from the decayed lining of the Broad Street pump. The committee further inferred that the likely index case of the Golden Square outbreak was an infant with cholera who died at 40 Broad St on September 2 and whose diapers were rinsed over the house's cesspool, thus contaminating the pump. Since that infant's death was attributed in vital records to diarrhea and not to cholera, Snow was unaware of it, and his spot map noted only four deaths at 40 Broad St.

Neither Snow nor the CSI appear to have known, at the time of their writing, about the relationship of the cesspool at 40 Broad St to the Broad Street pump. The CSI was unpersuaded by Snow's inferential reasoning:

> In explanation of the remarkable intensity of this outbreak within very definite limits, it has been suggested by Dr. Snow, that the real cause of whatever was peculiar in the case lay in the use of one particular well, situate at Broad Street in the middle of the district, and having (it was imagined) its waters contaminated with the rice-water evacuations of cholera patients. After careful inquiry, we see no reason to adopt



Note. a = amphileptus, b = monads and other infusoria, c = brown ova cases.
Source. Appendix to Report of the CSI, Plate 9 (opp p 238).[6]

FIGURE 4—Sample of water from the Broad Street pump.

> this belief. We do not find it established that the water was contaminated in the manner alleged; nor is there before us any sufficient evidence to show whether inhabitants of that district, drinking from that well, suffered in proportion more than other inhabitants of the district who drank from other sources.[21]

The CSI's conclusions about the cholera epidemic of 1854 reflected a view of epidemic diseases quite different from that of John Snow. In the first place, the CSI was steadfastly anticontagionist and rejected Snow's view that cholera could be transmitted person to person. Victorian sanitarians of the pre-Pasteur era were almost uniformly anticontagionist[22] and tended to attribute cholera (and most other epidemic diseases) to the influence of decaying organic matter and its vaporous emanations or "miasma."[23] The effect of these emanations was nonspecific—under the right epidemic circumstances they could lead to cholera, typhoid, ordinary diarrhea, or typhus ("jail fever," as it was then known). Cholera was thus thought to be acquired principally by the airborne route, and from nonhuman sources. By the 1840s, probably influenced by the theories of the German physician and chemist Justus Liebig,[24] leading scientific sanitarians such as Simon and Farr no longer considered stagnant water, swampy conditions, and rotting organic matter to be direct causes of diseases themselves, but as raw materials to be operated upon by disease "ferments" present in the atmosphere during epidemics.[25] These ferments catalyzed the putrefying material in the environment to produce lethal illness in predisposed individuals. This concept led Farr to refer to "epidemic, endemic and contagious diseases" as "zymotic" (*zyme* meaning "ferment")[26] Although the wandering ferment could not be directly attacked, its influence could be modified, the sanitarians thought, by removing the environmental impurities:

> [T]he undiscovered power in its [i.e., epidemic cholera's] wanderings acts after the manner of a *ferment,* that it therefore takes effect only amid congenial circumstances, and that the stuff out of which it brews poison must be air or water abounding with organic impurity. Taking this as hypothesis, and testing it with the facts before us, we find that it would include and explain them. Either in air or water, it seems probable that the infection can grow. Often it is not easy to say which of these media may have been the chief scene of poisonous fermentation; for the impurity of one commonly implies the impurity of both; and in considerable parts of the metropolis (where the cholera has severely raged) there is rivalry of foulness between the two. But, 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 to the air.[27]

Snow, on the other hand, believed that the agent of cholera was specific to cholera and that it was most likely a live organism. The purely gastrointestinal manifestations of cholera led Snow to believe that this life form was ingested accidentally from fecally contaminated sources and not inhaled, that the agent multiplied in the body before the onset of disease (producing an incubation period that Snow accurately observed to be 24 to 48 hours), and that it was passed, in contagious form, in the victim's rice-water stools. Raw sewage containing evacuations of cholera patients was therefore potentially infectious—and actually so when sewage contaminated water supplies.

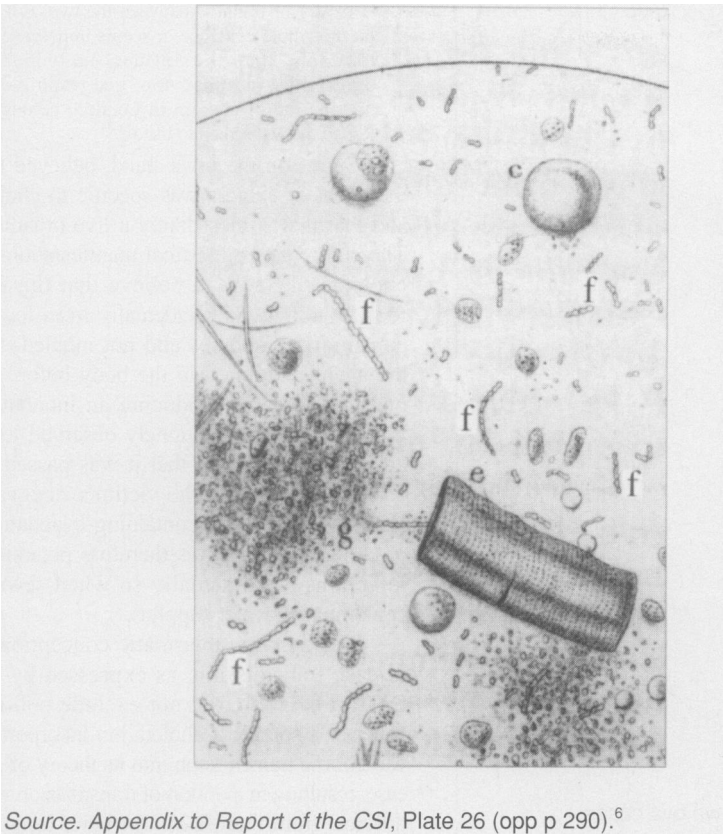
The zymotic-miasmatic conception of disease transmission, as expressed by the Board of Health, did not exclude polluted water as a source of cholera but incorporated waterborne transmission into its theory of disease, resulting in a notion of transmission very different from Snow's. As the chief Board of Health inspector, John Sutherland, put it:

> There is a difference of opinion concerning the part which impure water plays in the phenomena. It is believed by some, that the water which induces cholera contains the specific poison of cholera in it, probably derived from the evacuations of cholera patients; while others believe there is no sufficient evidence of this being the case, and they consider that all the facts go to prove that water containing putrescent organic matter acts as a very powerful predisposing cause of the pestilence in a similar way as does putrescent organic matter introduced into the system by the atmosphere or by food, but not as a specific poison.[28]

Although both schools of thought refer to the agent of cholera as a "poison," the zymotic-miasmatists who accepted the possibility of waterborne transmission viewed the organic pollutants in water as a substrate ("predisposing cause") for the ferment that "brews poison." The Board of Health did not go deeply into the theoretical ramifications of the disagreement, however; the authors' concerns at the time were practical and utilitarian. Sutherland (p. 40) went on to say:

> The matter in dispute is really of no great practical value, for if it be a fact that the use of impure water is dangerous to the public health, the manner of its action is of very secondary importance, at least for practical purposes.

In 1856, the Board of Health issued a separate report on the influence of impure



Source. Appendix to Report of the CSI, Plate 26 (opp p 290).[6]

FIGURE 5—Sample of rice-water evacuations, showing vibriones (labeled f).

water on the cholera epidemic (see note 6). Authored solely by John Simon, this brief report described associations between cholera and a tainted water supply in South London very similar to those that Snow had published in 1855. Like Snow, Simon referred to the situation in South London as an experiment, and in remarkably similar language.[29] In spite of this and many other similarities between the 2 studies, no mention is made of Snow in Simon's report.[30]

Sutherland's view that differences of opinion between zymotic-miasmatists and contagionists mattered little, since both theories led to a commitment to clean up the water supply, was seconded in 1927 by the British public health official Sir Arthur Newsholme, who knew Chadwick and Simon personally:

> It is arguable that the great campaign against filth urged with unrivaled eloquence and force by Simon, and forming the main item in the sanitary work of Chadwick and Southwood Smith, was remarkably effective also in securing clean supplies of water for the public.[31]

In reality, however, the differences in theory had major implications for public health action. Substantial resources were devoted, for example, to spreading lime on the streets of Golden Square during the outbreak as an antidote to putrescent vapors.[32] Miasmatists excluded the possibility of direct contagion, and therefore made no provision for isolation of patients or for nursing practices that would minimize spread of disease. Even Newsholme believed that

> had not the earlier sanitary leaders, Chadwick and Southwood Smith been so "anti-contagionist" in their views, more rapid progress might have been realized. Pettenkofer's views [see note 33] had great influence on the sanitary advisors in England, and must, I think, be credited with responsibility for the inadequate emphasis which in the earlier years was placed on the special sanitary improvement, viz., a perfectly safe water supply, which would bring about the most rapid reduction of disease.[31]

The Board of Health concluded that 3 convergent factors—stagnant air due to lack of wind, high barometric pressure, and high river water temperature at night—produced emanations from the Thames of nocturnal clouds of vapor laden with impurities, which were the raw material that, when catalyzed by the cholera ferment in the atmosphere, induced cholera in epidemic proportions. This theory was also used to explain Farr's observation that cholera was rarer at higher elevations—contaminated vapor clouds hugged the ground at lower elevations.

The Science of Snow and the Board of Health Contrasted

Ultimately, the Board's extensive investigations failed to produce much of lasting value, and Hassall, who might, with a different mind-set, have been credited (almost 30 years before Koch) with discovering the organism that causes cholera, is little remembered.[34] Snow, by contrast, has frequently been held up as an exemplar of scientific excellence in epidemiology. Contrasting Snow's scientific methodology with that of the Board of Health may illuminate some methodological issues in contemporary epidemiology.

In the first place, although the Board of Health had a general hypothesis about the cause of cholera, this hypothesis did not strongly guide the CSI investigators in their approach, except perhaps to indicate the most important topics for investigation. Certainly the CSI's theory of disease origin contributed to the extraordinary emphasis on describing atmospheric conditions before and during the epidemic, and to the documentation of unsanitary conditions. But once these areas were specified, the CSI investigators relied on an essentially inductionist methodology, piling example upon example and relying almost solely on the accumulation of positive evidence to support their hypothesis. There is little evidence that the CSI used this hypothesis to predict disease occurrence except in the very broadest sense. The Board's investigative teams sought repeatedly to document the correlation between cases of cholera and various indicators of neighborhood filth, but they paid little attention to the many instances in which people living in clean circumstances became ill or slum dwellers escaped the pestilence. In the words of the CSI quoted above, "Taking this as hypothesis, and testing it with the facts before us, we find that it would include and explain them."

By contrast, Snow's hypothesis was narrowly focused. Its predictions were specific enough that only a few observations were consistent with it, and many were potentially contradictory. Cholera incidence was determined by water supply, both at the individual level and at the group level; the finding of low attack rates of cholera in parts of the Golden Square neighborhood near the Broad Street pump was a direct challenge to Snow's hypothesis.

Because of its generality, the CSI zymosis-

HOUSE AND PREMISES	
No. of rooms	11
Source of water supply	(?) New River Co.; 3 cisterns
Whence drank	Cisterns
Necessaries	Panned privy
Ventilation	Fair, but closed in to the east; very foul
Dustbins	In front area
General State of Premises	Bad smells from water-closet at no. 7, Cambridge Street, in back parlours; perceived for a long time
Complaints of Outward Nuisances	Bad smells from street
INHABITANTS	
No. of Inmates	19 or 20
Employments and Habits	Carpenter, &c.
DISEASE	
Cholera cases	5
Cholera deaths	5 (1 away)
Diarrhea cases	. . .
Diarrhea deaths	. . .
Particulars as to Rooms Attacked	Ground floor, 2 deaths 1st floor, 2 deaths Top floor, 1 death
Particulars as to Persons Attacked	Policeman and child Tailor and wife Young man, tailor; well conducted. 1 woman said to have died of fright

FIGURE 6—Description of 40 Broad St by investigators from the General Board of Health.

miasma theory predicted too much and was therefore difficult to contradict or falsify. The specificity of Snow's hypothesis has sometimes been criticized by historians; both P. E. Brown and Margaret Pelling, for example, see Snow's refusal to allow for airborne transmission as evidence of narrowness of vision.[35]

But the strength of Snow's hypothesis lies in its exclusion of other alternatives; by insisting on a singular mode of transmission, Snow was able to imagine circumstances that would invalidate his hypothesis. The exemption of the Golden Square brewery workers from the cholera epidemic had no special meaning to the CSI but had a great deal of significance to Snow, as it led him immediately to a consideration of the brewery workers' distinctive water supply. Had they been drinkers of Broad Street pump water, Snow's theory would have suffered a heavy blow. As exceptions, the brewery workers were as significant a verification of Snow's hypothesis as were the cholera victims who used the Broad Street pump. Snow was eager to subject his hypothesis to the test; each counterexample—the healthy brewery workers, the cholera-afflicted children living nearer to another pump (but who passed by the Broad Street pump on their way to school), the widow who died of cholera in disease-free Hampstead (but who imported Broad Street pump water)—was an opportunity to see whether the hypothesis stood up to a challenge. No such challenging examples are seen in the CSI report.

An additional distinction between the contending hypotheses was their relationship to disease pathophysiology. The specificity of Snow's hypothesis is closely linked to his comprehensive understanding of the disease process in cholera. The hypothesis of waterborne transmission was based not just on epidemiologic observations, but on clinical and pathophysiological observations. Snow insisted that the disease was gastrointestinal, that indeed all of the disease's symptoms could be explained by fluid loss from the gastrointestinal tract. This led him to conclude that the portal of entry for the infecting agent was oral and not respiratory.[36]

Snow's formulation of cholera pathophysiology included insight into the likely cellular mechanism of cholera, including the concept of damage to the absorptive capacity of the intestines, and also such extracellular phenomena as the incubation period, life cycle, reservoir, and mode of transmission of the agent.

By contrast, the CSI discussed cholera pathophysiology only cursorily and made no attempt to link the zymosis-miasma theory to the clinical and pathological manifestations of cholera. The Board's scientists understood many of the biological processes that Snow considered when formulating his hypothesis, including the relationship between the large volume of fluid loss and vascular collapse. But the Board did not seek to connect the pathophysiology of cholera with its explanation of cholera's origin. One of Snow's great achievements was to develop a hypothesis of disease etiology coherent with his observations of the disease process itself and his reasoning about the probable pathophysiologic changes occurring in cholera.[37]

Implications for Contemporary Epidemiology

A major causal criterion used by epidemiologists to evaluate the validity of a proposed cause-and-effect linkage in epidemiology is coherence—that is, whether the epidemiologic model being proposed is consistent with what else is known about the biology of the disease under investigation.[38] Another important causal criterion is specificity, that is, that the putative exposure–disease relationship pertains to a specific exposure and/or a specific disease. Not often emphasized in epidemiologic teaching is that these two criteria are linked in the process of hypothesis formulation and hypothesis testing. Coherence in an epidemiologic hypothesis leads to specificity of prediction. A hypothesis well grounded in the pathophysiology of the disorder under investigation is more likely to lead to specific predictions of disease occurrence or attack rates than is a hypothesis based on a limited understanding of disease mechanisms. Both coherence and specificity are thus linked to the use of the hypothetico-deductive approach in epidemiology. This approach asserts that for a hypothesis to be valuable to science, it must be able to predict circumstances that would invalidate it, and, further, that it is just these circumstances that the investigator most profitably pursues.

The distinct scientific approaches of Snow and the Board of Health have counterparts in contemporary epidemiology. Studies that follow the Board of Health model have 3 characteristics: (1) a broad or general hypothesis, with which many observations can be consistent; (2) a tendency to treat negative findings, those that fail to confirm the hypothesis, as random events or type II errors that need not be pursued; and (3) an epidemiologic hypothesis that is not closely linked to the disease process under investigation.

Critics have termed aspects of this approach "black box epidemiology," but an epidemiologic research agenda not too strongly grounded in biology has its defenders.[39,40] To be fair, there are circumstances in epidemiology, particularly during initial investigations of poorly understood diseases, when induction is necessary to permit any hypothesis formulation. But for epidemiology that advances beyond the descriptive, John Snow's hypothetico-deductive approach is a distinctive model. This approach is specific in focus and prediction, anchored in a detailed understanding of the disease process under investigation, and open to—indeed, stimulated by—findings contrary to the hypothesis.

Snow referred to his studies of the South London water supply and cholera as a naturally occurring experiment. In fact, a great epistemological experiment also took place in London in 1854, namely, the contrast between Snow's hypothetico-deductive model of scientific investigation and the more inductive model employed by the Board of Health. In this instance, we conclude that the hypothetico-deductive model was more effective in clarifying the etiology and transmission of cholera and in proposing preventive measures. Whether this hypothesis is true under all circumstances, however, can be supported only by repeated attempts at refutation. □

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Endnotes

1. John Snow. *On the Mode of Communication of Cholera,* 2nd ed., much revised (London: Churchill, 1855; reprint, with an introduction by W. H. Frost, New York: Commonwealth Fund, 1936).
2. Vestry of St. James, Westminster, *Report on the Cholera Outbreak by the Cholera Inquiry Committee* (London: Churchill, 1855).
3. William T. Sedgwick, *Principles of Sanitary Science and the Public Health* (New York: Macmillan, 1914), 170–181.
4. Charles Edward Amory Winslow, *The Conquest of Epidemic Disease* (Princeton: Princeton University Press, 1944), 275.
5. SPW Chave. "John Snow, the Broad Street Pump and After," *Medical Officer* 99 (1958): 347–349.
6. The four reports and the appendix, all published by Her Majesty's Stationery Office in London, were as follows: *Letter of the President General Board of Health to the Right Honourable the Viscount Palmerston Accompanying a Report From Dr. Sutherland on Epidemic Cholera in the Metropolis in 1854* (1855, 120 pp); *Report of the Medical Council to the Right Honourable Sir Benjamin Hall, Bart., M.P., in Relation to the Cholera-Epidemic of 1854* (1855, 24 pp); *Report of the Committee for Scientific Inquiries in Relation to the Cholera-Epidemic of 1854* (1855, 129 pp); *Appendix to Report of the Committee for Scientific Inquiries in Relation to the Cholera Epidemic of 1854* (1855, 3512 pp); *Report on the Last Two Cholera Epidemics of London as Affected by the Consumption of Impure Water by the Medical Officer of the Board [John Simon]* (1856, 35 pp).
7. Margaret Pelling, *Cholera, Fever and English Medicine 1825–1865* (Oxford: Oxford University Press, 1978), 222.
8. Brief mentions of this report can be found in John Simon, *English Sanitary Institutions,* 2nd ed; (London: Smith-Elder, 1897); William Jephson, *The Sanitary Evolution of London* (Brooklyn, NY: A. Wessels, 1907), 73–77; Sir Arthur Newsholme, *Evolution of Preventive Medicine* (Baltimore: Williams & Wilkins, 1927), 150; Royston Lambert, *Sir John Simon* (London: MacGibbon & Kee, 1963), 227–228; and John Eyler, *Victorian Social Medicine* (Baltimore: Johns Hopkins, 1979), 118, but none of these authors deal with the report's scientific procedures or findings. The only discussion of the report's science we have found is in Pelling, *Cholera, Fever and English Medicine,* but the author does not describe the report's scientific observations in any detail.
9. G. Rosen, *A History of Public Health* (New York: MD Publications, 1958), 211.
10. The great bell in the clock tower of the Houses of Parliament is called Big Ben after this dedicated public servant.
11. The latter committee was unable to obtain any information and issued no report.
12. Neil Arnott, like Southwood Smith, authored a medical supplement to the 1838 Poor Law Report; Baly was coauthor of the 1852 report on cholera of the Royal College of Physicians and was physician to the Millbank penitentiary; Owen served on the Royal Commission to investigate the Public Health Act in 1843 and on the Metropolitan Sanitary Commission of 1847–1848. Farr and Simon, of course, are among the most outstanding public health figures of the 19th century.
13. Thomson's later role in controversies about the relative salubrity of London's water sources is described in Christopher Hamlin, *A Science of Impurity. Water Analysis in 19th Century Britain* (Bristol: Adam Hilger, 1990).
14. Arthur Hill Hassall, *Food and Its Adulterations* (London: Longman, Brown, Green & Longmans, 1855). This book summarizes in one place many of the findings about food adulteration published by Hassall in *The Lancet* in the 1840s. Hassall is now best remembered for the thymic corpuscle that bears his name.
15. The tank was half-filled with water, then drained from below to create suction that pulled air into the tank. Glass pipes were placed on the ceiling of the hospital ward and connected to two distilled water bottles through which the air had to pass before being sucked into the tank, to which the bottles were also attached by rubber tubing.
16. *Appendix to Report of the Committee for Scientific Inquiries [CSI],* 131.
17. *Appendix to Report of the CSI,* 289.
18. *Appendix to Report of the CSI,* 291.
19. The Italian microscopist Filippo Paccini concluded during the 1854 Florence epidemic that these vibriones, so plentiful in stool samples of cholera patients, were the cause of cholera; he named them *Vibrio cholera* (Filippo Paccini, *Osservazioni microscopische e deduzioni patologische sul Cholera Asiatico* [Florence: Tipografia Bencini, 1854]). Paccini, not Koch, is officially recognized by bacteriologists as the discoverer of the cholera bacillus (Judicial Commission of the International Committee on Bacterial Nomenclature, "Conservation of the Vibrio Paccini 1854 as a Bacterial Generic Name, Conservation of Vibrio Cholerae Paccini 1854 as the Nomenclatural Type Species of the Bacterial Genus Vibrio, and Designation of the Neotype Strain of Vibrio Cholerae Paccini," *International Bulletin of Bacteriological Nomenclature and Taxonomy* 15 [1965]: 185–186). For more details of Paccini's life and accomplishments, including his description of the Paccinian corpuscle, see M. Bentivoglio & P. Pacini, "Filippo Pacini: A Determined Observer," *Brain Research Bulletin* 38 (1995): 161–165.
20. Snow (44) identifies his source as "Dr. Fraser of Oakley Square," not as an investigator for the Board of Health. It is ironic indeed that the piece of evidence often viewed as showing the strongest support for Snow's hypothesis, the cholera attack of the Hampstead widow, was uncovered by a physician working for the Board of Health Committee on Scientific Inquiries.
21. *Report of the Committee on Scientific Inquiries [CSI],* 52.
22. Erwin Ackernecht, in his influential paper "Anticontagionism Between 1821 and 1867" (*Bulletin of the History of Medicine* [1948]:22; 562–593), cites several public health authorities, including William Welch and C. E. A. Winslow, to support this view.
23. One of the clearest descriptions of what is usually referred to as "miasma theory" is to be found in Thomas Southwood Smith, *A Treatise on Fever* (London: Longman, Rees, Orme, Brown & Green, 1830), especially 348–374. Southwood Smith provides clear definitions of the variety of terms used to label the different forms of noxious emanations of rotting matter. *Miasma* referred to gases emanating from naturally occurring swamps, *effluvia* to gases from rotting organic matter of vegetable or animal (but not human) origin, and *exhalations* to the breath or skin emanations of individuals with epidemic febrile illnesses. Other authors, including Farr and Simon, however, did not strictly adhere to this nosology, and used these terms almost interchangeably.
24. Liebig attempted to explain biological phenomena in chemical terms. Processes such as fermentation and putrefaction were viewed as chemical, and Liebig denied that yeast was a live organism. Contagious diseases were viewed as instances of fermentative processes occurring in the bloodstream, provoked by a nonliving chemical agent that was dependent on raw materials in the blood for its own reproduction (Liebig, *Chemistry in its Application to Agriculture and Physiology* [German ed. of 1840, ed. and trans. Lyon Playfair], 1841; Philadelphia: T. B. Peterson, 1850), 115–129. Snow's insis-

tence on the nonhematogenous nature of cholera distances him from this theory, with which he was familiar.

25. Historians are divided on the influence of Liebig on British sanitarians. Margaret Pelling and John Eyler consider his influence substantial, especially on Farr, but Royston Lambert (49) states that in England, Liebig's theories received "negligible support."
26. [William Farr,] *Appendix to the 4th Annual Report, 8vo, of the Registrar General*, 199–205, cited in *Report on the Mortality of Cholera in England, 1848–49* (London: Her Majesty's Stationery Office, 1852) p. lxxx.
27. *Report of the CSI*, 48.
28. *Letter of the President*, 40.
29. Snow in 1855: "[N]o experiment could have been devised which would more thoroughly test the effect of water supply on the progress of cholera. . . . The experiment too was on the grandest scale. No fewer than 300,000 people of both sexes, of every age and occupation, and of every rank and station . . . were divided into two groups . . . one group being supplied with water containing the sewage of London, and, amongst it, whatever might have come from the cholera patient, the other having water quite free from such impurity." Snow, 75.

    Simon in 1856: "An experiment . . . has been conducted during two epidemics of cholera on 500,000 human beings. One half of this multitude was doomed in both epidemics to drink the same faecalized water. . . . while another section—freed in the second epidemic from that influence which had so aggravated the first, was happily enabled to evince . . . the comparative immunity which the cleanlier beverage could give." *Report of the Last Two Cholera Epidemics*, 9.
30. In his memoirs (*English Sanitary Institutions*, 261, n), Simon, referring to his 1856 report on the effect of impure water in the cholera epidemic, remarks "That the much larger inquiry which the board afterwards conducted had been suggested by Dr. Snow's original enterprise, may, I think, be assumed, for though I have neither record nor positive recollection how the Scientific Inquiries Committee came to recommend the larger inquiry, I can hardly doubt that the suggestion must have come to us from Dr. Farr, who had been intimately acquainted with the course of Dr. Snow's inquiry. . . ." Margaret Pelling (235) has noted that Snow protested Simon's failure to provide proper acknowledgment in a letter to the *British Medical Journal* in 1857 (ii, 864).
31. Newsholme, *Evolution*, 149–150.
32. "The Cholera in Golden Square," *Times of London*, 15 September 1854.
33. Max von Pettenkoffer (1818–1899) believed that the agent in cholera evacuations became infective only after it had spent an extended period in the earth and entered the groundwater. Attempting to prove this point, he once drank a glass of water into which 1 cc of rice-water evacuations had been poured, suffering only some mild diarrhea as a consequence.
34. In Hassall's aptly titled autobiography, *Memoirs of a Busy Life* (London: Longmans, Green, 1893), 76, he states, "[F]rom their general agreement with Koch's description, there is not the smallest doubt that the cholera bacillus was present in the discharges in nearly every case and was first seen by me during the cholera epidemic of 1854, now nearly 40 years since."
35. P. E. Brown, "John Snow—The Autumn Loiterer," *Bulletin of the History of Medicine* 35 (1961): 519–528; Pelling, *Cholera, Fever and English Medicine*, 207.
36. We might also consider, in this context, that Snow was the leading scientific authority on anesthetic gases of his day and had considerable experimental and clinical experience with the effects of inhaled chemical agents.
37. The Dutch epidemiologist Jan Vandenbroucke, while resistant to Snow hagiography (J. P. Vandenbroucke, H. M. Eelkman Rooda, and H. Beukers, "Who Made John Snow a Hero?" *American Journal of Epidemiology* 133 [1991]: 967–973), has nevertheless also emphasized the important lesson for contemporary epidemiology of Snow's linkage of epidemiology and pathophysiology (J. P. Vandenbroucke, "Which John Snow Should Set the Example for Clinical Epidemiology?" *Journal of Clinical Epidemiology* 12 [1988]: 1215–1216).
38. Of the several formulations of such causal criteria, one of the most recent is by Mervyn Susser ("What Is a Cause and How Do We Know One? A Grammar for Pragmatic Epidemiology," *American Journal of Epidemiology* 133 [1991]: 635–648).
39. D. A. Savitz, "In Defense of Black-Box Epidemiology," *Epidemiology* 5 (1994): 550–552.
40. R. Peto, "The Need for Ignorance in Cancer Research," in *The Encyclopedia of Medical Ignorance*, ed. R. Duncan and M. Weston-Smith (Oxford: Pergamon Press, 1984), 129–133.