CHAPTER 3

Snow on Cholera

INTRODUCTION: THE MAN, THE BACKGROUND

John Snow was born the son of a farmer in York, England, in 1813. At the age of 14 he was apprenticed to a surgeon in Newcastle, who sent him when he was 18 to attend the sufferers of a major outbreak of cholera in the vicinity. In 1838 he passed his examination in London and became a member of the Royal College of Surgeons. He quickly made significant contributions to medical research: he participated in the development of an air pump for administering artificial respiration to newborn children unable to breathe and invented an instrument for performing thoracic surgery. He made major contributions to the new technique of anesthesia, becoming the leading specialist in London in the administration of ether, but switching to the easier-to-use chloroform when his own experimental studies convinced him of its practicality. He administered chloroform to Queen Victoria on the birth of her children, Prince Leopold and Princess Beatrice. His greatest achievement was his study of cholera, which he described in his monograph "On the Mode of Communication of Cholera," one of the classics of scientific method and a fascinating story fascinatingly written. Snow died in 1858, a relatively young man, while at work on a book entitled *On Chloroform and Other Anaesthetics*.

The concept of communicable diseases—that some diseases are transmitted by close contact from the sick to the well—came into being in the Middle Ages.[1] The ancient Greeks were the first to attempt to look at disease scientifically. They rejected the idea of disease as a punishment for sin or as a consequence of witchcraft, and studied instead the relation of diseases to aspects of the natural environment or

the way men live, eat, and work. They noted, for example, that it was unhealthy to live near swamps. But in spite of the fact that they suffered from epidemics of various sorts, they somehow missed recognizing that some diseases are contagious.

The prescriptions for isolation and purification described in the Hebrew Bible for physiological processes such as menstruation and for diseases characterized by discharges or skin lesions apparently are based on the idea of the contagiousness of spiritual uncleanliness, of which the physical disease was merely an external symptom. In the Middle Ages, the Church, confronted with a major epidemic of leprosy, revived the biblical practice of isolation of the sick, and the same methods were applied during the outbreak of the Black Death (bubonic plague) in the fourteenth century. By this time the concept of contagion was well established.

It is interesting that the belief that disease was a consequence of evil behavior coexisted with the recognition of contagion for hundreds of years. Attempts to develop treatments for syphilis were opposed on the grounds that syphilis was a punishment for sexual immorality. Cholera was most prevalent among the poor for reasons that will become apparent, and there were many who regarded it also as a just punishment for the undeserving and vicious classes of society. A governor of New York State once stated during a cholera epidemic, "... an infinitely wise and just God has seen fit to employ pestilence as one means of scourging the human race for their sins, and it seems to be an appropriate one for the sins of uncleanliness and intemperance...." The President of New York's Special Medical Council stated at the onset of an epidemic in 1832, "The disease had been confined to the intemperate and the dissolute with but few exceptions." A newspaper report noted, "Every day's experience gives us increased assurance of the safety of the temperate and prudent, who are in circumstances of comfort.... The disease is now, more than before, rioting in the haunts of infamy and pollution. A prostitute at 62 Mott Street, who was decking herself before the glass at 1 o'clock yesterday, was carried away in a hearse at half past three o'clock. The broken down constitutions of these miserable creatures perish almost instantly on the attack.... But the business part of our population, in general, appear to be in perfect health and security." A Sunday School newspaper for children explained, "*Drunkards and filthy wicked people of all descriptions* are swept away in *heaps*, as if the Holy God could no longer bear their wickedness, just as we sweep away a mass of filth when it has become so corrupt that we cannot bear it.... The Cholera is not caused by intemperance and filth in themselves, but is a *scourge*, a rod in the hand of God."[2]

By the middle of the nineteenth century some of the major communicable diseases had been identified and well differentiated from each other. This was no easy task in itself. For example, a large number of children's diseases have as symptoms fever and a sore throat; these diseases are still not easy to distinguish today. There are many conditions associated with severe diarrhea, for example, cholera, typhoid, dysentery, bacterial food poisoning, noninfectious diseases of the lower intestine such as colitis, and poisoning with certain drugs. In the nineteenth century it had also been demonstrated that some of the contagious diseases could be artificially transmitted by inoculation of small amounts of "morbid matter" taken from the sick. The modes of transmission of particular diseases such as syphilis, intestinal worms, and skin diseases were known. Further, certain types of living organisms had been shown to cause disease directly: the itch mite in scabies as well as certain types of fungus in a disease of silkworms, in ringworm, and in other conditions. Bacteria and protozoa were discovered with the invention and further development of the microscope. These were often observed in the bodies of victims of certain diseases, and various scientists were beginning to speculate that they might be the cause of communicable diseases. The idea in various forms was in the air by the time of Snow, and he made use of it. Solid proof of the germ theory of disease came only in the 1860s and 1870s, after Snow's study, in the work of Pasteur and Koch.

THE DISEASE

Cholera is a bacterial disease characterized by severe diarrhea, vomiting, and muscular cramps. The diarrhea can produce extreme dehydration and collapse; death is frequent, and often occurs within hours after the onset of sickness.

The disease had been known to exist in India since the eighteenth century, and occurs there and in other parts of the world today. In the nineteenth century, as travel between Asia and the West became more common and as the crowding of people in urban centers increased as a result of the industrial revolution, major epidemics occurred in Europe and America. England had epidemics in 1831–32, 1848–49, and 1853–54.

The question of how cholera is transmitted was especially difficult. On the one hand there was good evidence that it could be transmitted by close personal contact. Yet there was equally good evidence that some

who had close personal contact with the sick, such as physicians, rarely got it, and that outbreaks could occur at places located at great distances from already existing cases of the disease.

A number of theories were proposed, some of which were too vague to be rationally examined but some of which had solid experimental support. A number of people, including both physicians and uneducated laymen, had blamed the water supply. Snow adopted this theory, but refined it by specifically implicating the excretions of the cholera victims.

Snow's genius lay not so much in hitting on the correct mechanism for the spread of the disease as in providing a beautiful and convincing experimental proof of it; he recognized the importance of the circumstance that, by chance, in a single district of London where an outbreak had occurred, some houses got their drinking water from one source and some from another.

That Snow made the case for his own theory so convincing did not relieve him of the obligation to test alternate theories and show that they did not explain the experimental observations as well as his own. We have collected in one section his discussions of these theories and his arguments against them.

The reader should be aware that Snow's theory did not, at the time he proposed it, explain every single experimental fact. There were some facts that did not fit, and others that were explained as well or better by other theories. Most successful scientific theories, especially when they are new, are in this position, and those who propose them must have the courage and the judgment to put discordant facts aside at times. There are obvious risks in doing this, but we could not advance without it. We will point out from time to time places where Snow's explanations of discordant facts are shaky.

INTRODUCTION TO THE STUDY

We have chosen to tell the story as much as possible in Snow's own words, partly because it conveys more of the direct personal experience of making a major scientific discovery, and partly because Snow tells it so well. Page references are to *Snow on Cholera*, a reprint of two of Snow's major monographs, published by the Commonwealth Fund, New York, 1936. All quotations are from "On the Mode of Communication of Cholera," originally published in 1854. All italics are ours. In the selections from the monograph we have mostly followed Snow's order

of presentation except in a few cases where logical clarity is achieved by deviating from it.

Snow begins with a brief historical review, following which he cites evidence to show that cholera can be transmitted by close personal contact with the sick:

The History of Cholera

The existence of Asiatic Cholera cannot be distinctly traced back further than the year 1769. Previous to that time the greater part of India was unknown to European medical men; and this is probably the reason why the history of cholera does not extend to a more remote period. It has been proved by various documents, quoted by Mr. Scot, that cholera was prevalent at Madras in the year above mentioned, and that it carried off many thousands of persons in the peninsula of India from that time to 1790. From this period we have very little account of the disease till 1814, although, of course, it might exist in many parts of Asia without coming under the notice of Europeans....

In 1817, the cholera prevailed with unusual virulence at several places in the Delta of the Ganges; and, as it had not been previously seen by the medical men practising in that part of India, it was thought by them to be a new disease. At this time the cholera began to spread to an extent not before known; and, in the course of seven years, it reached, eastward, to China and the Philippine Islands; southward, to the Mauritius and Bourbon; and to the north-west, as far as Persia and Turkey. Its approach towards our own country, after it entered Europe, was watched with more intense anxiety than its progress in other directions.

It would occupy a long time to give an account of the progress of cholera over different parts of the world, with the devastation it has caused in some places, whilst it has passed lightly over others, or left them untouched; and unless this account could be accompanied with a description of the physical condition of the places, and the habits of the people, which I am unable to give, it would be of little use.

General Observations on Cholera

There are certain circumstances, however, connected with the progress of cholera, which may be stated in a general way. It travels along the great tracks of human intercourse, never going faster than people travel, and generally much more slowly. In extending to a fresh island or continent, it always appears first at a sea-port. It never attacks the crews of ships going from a country free from cholera, to one where the disease is prevailing, till they have entered a port, or had intercourse with the shore. Its exact progress from town to town cannot always be traced; but it has never appeared except where there has been ample opportunity for it to be conveyed by human intercourse. (pp. 1–2)

Cholera is Contagious

It was important to demonstrate that cholera was indeed a contagious disease, transmittable by contact with victims of the disease. Snow cites the following examples to prove this. In each of them, the occurrence of several cases among members of a single family or among people living in close proximity at a time when no other cases of the disease existed in the vicinity would be hard to explain unless contagion or a common source of infection were at work.

> There are also innumerable instances which prove the communication of cholera, by individual cases of the disease, in the most convincing manner. Instances such as the following seem free from every source of fallacy. (pp. 1–2)

> I called lately to inquire respecting the death of Mrs. Gore, the wife of a labourer, from cholera, at New Leigham Road, Streatham. I found that a son of the deceased had been living and working at Chelsea. He came home ill with a bowel complaint, of which he died in a day or two. His death took place on August 18th. His mother, who attended on him, was taken ill on the next day, and died the day following (August 20th). There were no other deaths from cholera registered in any of the metropolitan districts, down to the 26th August, within two or three miles of the above place.... (p. 3)

> John Barnes, aged 39, an agricultural labourer, became severely indisposed on the 28th of December 1832; he had been suffering from diarrhea and cramps for two days previously. He was visited by Mr. George Hopps, a respectable surgeon at Redhouse, who, finding him sinking into collapse, requested an interview with his brother, Mr. J. Hopps, of York. This experienced practitioner at once recognized the case as one of Asiatic cholera; and, having bestowed considerable attention on the investigation of that disease, immediately enquired for some probable source of contagion, but in vain: no such source could be discovered....
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> Whilst the surgeons were vainly endeavouring to discover whence the disease could possibly have arisen, the mystery was all at once, and most unexpectedly, unravelled by the arrival in the village of the son of the deceased John Barnes. This young man was apprentice to his uncle, a shoemaker, living at Leeds. *He informed the surgeons that his uncle's wife (his father's sister) had died of cholera a fortnight before that time, and that, as she had no children, her wearing apparel had been sent to Monkton by a common carrier. The clothes had not been washed; Barnes had opened the box in the evening; on the next day he had fallen sick of the disease.*
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> During the illness of Mrs. Barnes, [the wife of John Barnes: she and two friends who visited Barnes during his illness also got cholera], her mother, who was living at Tockwith, a healthy village 5 miles distant from Moor Monkton, was requested to attend her. She went to Monkton accordingly, remained with her daughter for 2 days, washed her daughter's linen, and set out on her return home, apparently in good health. Whilst in the act of walking home she was seized with the malady, and fell down

in collapse on the road. She was conveyed home to her cottage, and placed by the side of her bedridden husband. He, and also the daughter who resided with them, took the malady. All the three died within 2 days. Only one other case occurred in the village of Tockwith, and it was not a fatal case....

It would be easy, by going through the medical journals and works which have been published on cholera, to quote as many cases similar to the above as would fill a large volume. *But the above instances are quite sufficient to show that cholera can be communicated from the sick to the healthy; for it is quite impossible that even a tenth part of these cases of consecutive illness could have followed each other by mere coincidence, without being connected as cause and effect....* (p. 9)

How Does Cholera Spread? The "Effluvia" Theory

The transmission of contagious diseases was frequently explained by "effluvia" given off in the exhalations of the patient or from bodies of the dead and subsequently inhaled into the lungs of a healthy person. (The reader should bear in mind that the germ theory was only a speculation at this time, and was not widely believed by doctors.) Snow now points out two arguments against this theory: (1) not everyone in close contact with a patient gets the disease, even though anyone having close contact breathes the "effluvia" given off in the exhalations of the patient, and (2) sometimes cholera breaks out during an epidemic in new areas remote from other cases, where there has been no opportunity for exposure to "effluvia."

> Besides the facts above mentioned, which prove that cholera is communicated from person to person, there are others which show, first, that being present in the same room with a patient, and attending on him, do not necessarily expose a person to the morbid poison; and, secondly, that it is not always requisite that a person should be very near a cholera patient in order to take the disease, as the morbid matter producing it may be transmitted to a distance. It used to be generally assumed, that if cholera were a catching or communicable disease, it must spread by effluvia given off from the patient into the surrounding air, and inhaled by others into the lungs. This assumption led to very conflicting opinions respecting the disease. A little reflection shows, however, that we have no right thus to limit the way in which a disease may be propagated, for the communicable diseases of which we have a correct knowledge spread in very different manners. The itch, and certain other diseases of the skin, are propagated in one way; syphilis, in another way; and intestinal worms in a third way, quite distinct from either of the others.... (pp. 9–10)

Snow here gives another argument against the effluvia theory: cholera begins without any prior evidence of a systemic infection, but rather with intestinal symptoms directly, whereas if it resulted from

breathing in a poison there should be some evidence of general illness first.

> A consideration of the pathology of cholera is capable of indicating to us the manner in which the disease is communicated. If it were ushered in by fever, or any other general constitutional disorder, then we should be furnished with no clue to the way in which the morbid poison enters the system; whether, for instance, by the alimentary canal, by the lungs, or in some other manner, but should be left to determine this point by circumstances unconnected with the pathology of the disease. But from all that I have been able to learn of cholera, both from my own observations and the descriptions of others, I conclude that cholera invariably commences with the affection of the alimentary canal. The disease often proceeds with so little feeling of general illness, that the patient does not consider himself in danger, or even apply for advice, till the malady is far advanced. . . .
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> In all the cases of cholera that I have attended, the loss of fluid from the stomach and bowels has been sufficient to account for the collapse, when the previous condition of the patient was taken into account, together with the suddenness of the loss, and the circumstance that the process of absorption appears to be suspended. . . . (pp. 10–11)

Diseases which are communicated from person to person are caused by some material which passes from the sick to the healthy, and which has the property of increasing and multiplying in the systems of the persons it attacks. In syphilis, small-pox, and vaccinia, we have physical proof of the increase of the morbid material, and in other communicable diseases the evidence of this increase, derived from the fact of their extension, is equally conclusive. As cholera commences with an affection of the alimentary canal, and as we have seen that the blood is not under the influence of any poison in the early stages of this disease, *it follows that the morbid material producing cholera must be introduced into the alimentary canal—must, in fact, be swallowed accidentally, for persons would not take it intentionally; and the increase of the morbid material or cholera poison, must take place in the interior of the stomach and bowels.* It would seem that the cholera poison, when reproduced in sufficient quantity, acts as an irritant on the surface of the stomach and intestines, or, what is still more probable, it withdraws fluid from the blood circulating in the capillaries, by a power analogous to that by which the epithelial cells of the various organs abstract the different secretions in the healthy body. For the morbid matter of cholera having the property of reproducing its own kind, must necessarily have some sort of structure, most likely that of a cell. It is no objection to this view that the structure of the cholera poison cannot be recognized by the microscope, for the matter of small-pox and of chancre can only be recognized by their effects, and not by their physical properties.

The period which intervenes between the time when a morbid poison enters the system, and the commencement of the illness which follows, is called the period of incubation. It is, in reality, a period of reproduction, as regards the morbid matter; and the disease is due to the crop or progeny resulting from the small quantity of poison first introduced. In cholera, this period of incubation or reproduction is much shorter than in most other epidemic or communicable diseases. From the cases previously de-

> tailed, it is shown to be in general only from 24 to 48 hours. It is owing to this shortness of the period of incubation, and to the quantity of the morbid poison thrown off in the evacuations, that cholera sometimes spreads with a rapidity unknown in other diseases. . . .(pp. 16–17)

Note Snow's speculation, "For the morbid matter of cholera, having the property of reproducing its own kind, must necessarily have some sort of structure, most likely that of a cell." The theory that contagious diseases are caused by microorganisms had been proposed, as noted, by others before Snow, using the same argument. Convincing confirmation did not come for another 20–30 years.

In the first sentence of the next quotation, Snow states the basic hypothesis of his work.

Snow's Theory

> The instances in which minute quantities of the ejections and dejections of cholera patients must be swallowed are sufficiently numerous to account for the spread of the disease; and on examination it is found to spread most where the facilities for this mode of communication are greatest.

In the following, Snow points out that people belonging to different social classes perform different functions around the sick, live in different kinds of houses, and have different personal habits and lifestyles. The result is that they have different risks of catching diseases.

Why Doctors Didn't Get Cholera and Those Laying Out the Body Did

> Nothing has been found to favour the extension of cholera more than want of personal cleanliness, whether arising from habit or scarcity of water, although the circumstance till lately remained unexplained. The bed linen nearly always becomes wetted by the cholera evacuations, and as these are devoid of the usual colour and odour, the hands of persons waiting on the patient become soiled without their knowing it; and unless these persons are scrupulously cleanly in their habits, and wash their hands before taking food, they must accidentally swallow some of the excretion, and leave some on the food they handle or prepare, which has to be eaten by the rest of the family, who, amongst the working classes, often have to take their meals in the sick room: hence the thousands of instances in which, amongst their class of the population, a case of cholera in one member of the family is followed by other cases; whilst medical men and others, who merely visit the patients, generally escape. The post mortem inspection of the bodies of cholera patients has hardly ever been followed by the disease that I am aware, this being a duty that is necessarily followed by careful washing of the hands; and it is not the habit of medical men to be taking food on such an occasion. On the other hand, the duties performed about the body, such as laying it out, when done by women of the working class, who make the occasion one of eating and drinking, are often followed by

an attack of cholera; and persons who merely attend the funeral, and have no connexion with the body, frequently contract the disease, in consequence, apparently, of partaking of food which has been prepared or handled by those having duties about the cholera patient, or his linen and bedding.... (pp. 16–17)

Why the Rich Did Not Get Cholera So Often

The involuntary passage of the evacuations in most bad cases of cholera, must also aid in spreading the disease. Mr. Baker, of Staines, who attended 260 cases of cholera and diarrhea in 1849, chiefly among the poor, informed me... that "when the patients passed their stools involuntarily the disease evidently spread." It is amongst the poor, where a whole family live, sleep, cook, eat and wash in a single room, that cholera has been found to spread when once introduced, and still more in those places termed common lodging-houses, in which several families were crowded into a single room. It was amongst the vagrant class, who lived in this crowded state, that cholera was most fatal in 1832; but the Act of Parliament for the regulation of common lodging-houses, has caused the disease to be much less fatal amongst these people in the late epidemics. When, on the other hand, cholera is introduced into the better kind of houses, as it often is, by means that will be afterwards pointed out, it hardly ever spreads from one member of the family to another. The constant use of the hand-basin and towel, and the fact of the apartments for cooking and eating being distinct from the sick room, are the cause of this.... (p. 18)

We may recall the two observations cited by Snow against the "effluvia" hypothesis: (1) not everyone (such as doctors) having close contact with a cholera victim gets it, and (2) sometimes it appears at great distances from the nearest case. Note that Snow's hypothesis (communication through evacuation) explains the first observation plausibly. Now he deals with the second, by making an additional subsidiary hypothesis.

How Did Cholera Get to the Rich?

If the cholera had no other means of communication than those which we have been considering, it would be constrained to confine itself chiefly to the crowded dwellings of the poor, and would be continually liable to die out accidentally in a place, for want of the opportunity to reach fresh victims; but there is often a way open for it to extend itself more widely, and to reach the well-to-do classes of the community; I allude to the mixture of the cholera evacuations with the water used for drinking and culinary purposes, either by permeating the ground, and getting into wells, or by running along channels and sewers into the rivers from which entire towns are sometimes supplied with water.... (pp. 22–23)

In the following quotations Snow gives evidence for his second

hypothesis: *that cholera spreads through the water supply*. It should be noted that the idea that water is responsible was suggested by many others quoted by Snow: Mr. Grant, Dr. Chambers, Mr. Cruikshanks, and various other named and unnamed individuals. Snow's hypothesis, although it must have owed much to these people, is more specific in that it identifies the excretions of the victims as the source of the contamination of the water supply, and explains transmission by direct contact as well.

> In 1849 there were in Thomas Street, Horsleydown, two courts close together, consisting of a number of small houses or cottages, inhabited by poor people. The houses occupied one side of each court or alley—the south side of Trusscott's Court, and the north side of the other, which was called Surrey Buildings, being placed back to back, with an intervening space, divided into small back areas, in which were situated the privies of

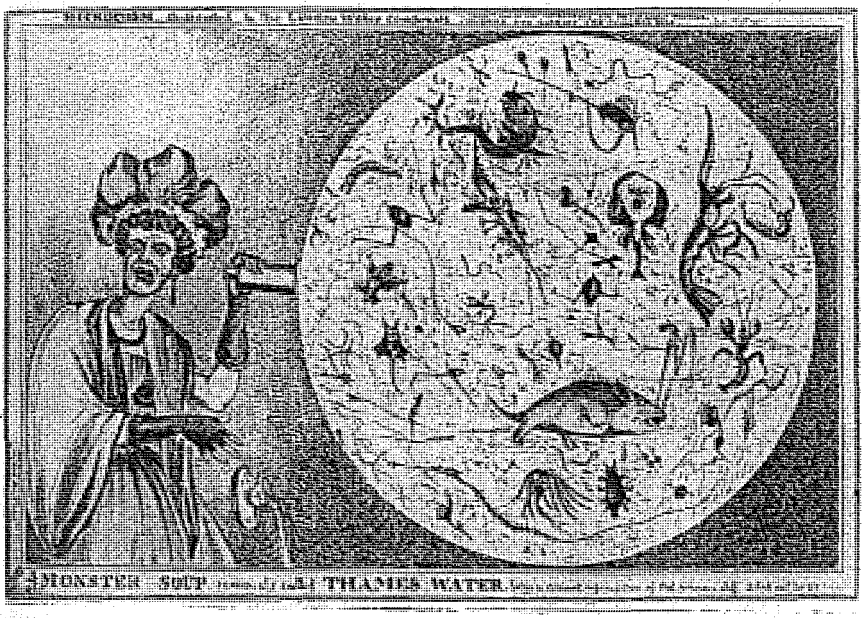

FIGURE 4. "Monster soup commonly called Thames Water." Etching by William Heath, *ca.* 1828. The pollution of the London water supply was not a discovery of John Snow. This etching was apparently a response to a report of a London Commission that investigated the water from the Thames, and reported it was "charged with the contents of the great common sewers, the drainings of the dunghills and laystalls, the refuse of hospitals, slaughterhouses, and manufactures." (Given by Mrs. William H. Horstmann to the Philadelphia Museum of Art, and reproduced with permission of the Museum.)

both the courts, communicating with the same drain, and there was an open sewer which passed the further end of both courts. *Now, in Surrey Buildings the cholera committed fearful devastation, whilst in the adjoining court there was but one fatal case, and another case that ended in recovery. In the former court, the slops of dirty water, poured down by the inhabitants into a channel in front of the houses, got into the well from which they obtained their water; this being the only difference that Mr. Grant, the Assistant-Surveyor for the Commissioners of Sewers, could find between the circumstances of the two courts as he stated in a report that he made to the Commissioners....* (p. 23)

In Manchester, a sudden and violent outbreak of cholera occurred in Hope Street, Salford. The inhabitants used water from a particular pump-well. This well had been repaired, and a sewer which passes within 9 inches of the edge of it became accidentally stopped up, and leaked into the well. The inhabitants of 30 houses used the water from this well; among them there occurred 19 cases of diarrhea, 26 cases of cholera, and 25 deaths. The inhabitants of 60 houses in the same immediate neighbourhood used other water; among these there occurred 11 cases of diarrhaea, but not a single case of cholera, nor one death. It is remarkable, that, in this instance, out of the 26 persons attacked with cholera, the whole perished except one.... (pp. 31–32)

The Washerwoman Was Spared

Dr. Thomas King Chambers informed me, that at Ilford, in Essex, in the summer of 1849, the cholera prevailed very severely in a row of houses a little way from the main part of the town. It had visited every house in the row but one. The refuse which overflowed from the privies and a pigsty could be seen running into the well over the surface of the ground, and the water was very fetid; yet it was used by the people in all the houses except that which had escaped cholera. That house was inhabited by a woman who took linen to wash, and she, finding that the water gave the linen an offensive smell, paid a person to fetch water for her from the pump in the town, and this water she used for culinary purposes, as well as for washing.

How the Landlord Got it

The following circumstance was related to me, at the time it occurred, by a gentleman well acquainted with all the particulars. The drainage from the cesspools found its way into the well attached to some houses at Locksbrook, near Bath, and the cholera making its appearance there in the autumn of 1849, became very fatal. The people complained of the water to the gentleman belonging to the property, who lived at Weston, in Bath, and he sent a surveyor, who reported that nothing was the matter. The tenants still complaining, *the owner went himself, and on looking at the water and smelling it, he said that he could perceive nothing the matter with it.* He was asked if he would taste it, *and he drank a glass of it. This occurred on a Wednesday; he went home, was taken ill with the cholera, and died on the Saturday following, there being no cholera in his own neighbourhood at the time....* (pp. 31–32)

THE FIRST EXPERIMENT: 1849

The Broad Street Pump

By the time of the 1849 outbreak of cholera in the vicinity of the Broad Street pump, described next, Snow already was convinced that cholera is spread through the water supply, but the data he was able to gather by close observation guided by his hypothesis made the case for it much more convincing. Because of his hypothesis, he asked certain questions and noticed certain things, for example, the high rate of the disease among the customers of a certain coffee shop, and the low rate among the inhabitants of a workhouse and the employees at a brewery.

He also took the first public health measure based on his ideas. He told the Board of Guardians of the parish to remove the handle of the Broad Street pump to prevent any further use of the contaminated water and thus any further cases of cholera arising from this source. He hoped that this would provide experimental proof of his theory. It would have done so if there had been a sudden drop in the number of new cases of the disease after the pump handle was removed. But in this he was disappointed. The epidemic had already passed its peak and the number of new cases was already falling rapidly.

"The Mortality in This Limited Area Equals Any That Was Ever Caused in This Country by the Plague"

> The most terrible outbreak of cholera which ever occurred in this kingdom is probably that which took place in Broad Street, Golden Square, and the adjoining streets, a few weeks ago. Within 250 yards of the spot where Cambridge Street joins Broad Street, there were upwards of 500 fatal attacks of cholera in 10 days. The mortality in this limited area probably equals any that was ever caused in this country, even by the plague; and it was much more sudden, as the greater number of cases terminated in a few hours. The mortality would undoubtedly have been much greater had it not been for the flight of the population. Persons in furnished lodgings left first, then other lodgers went away, leaving the furniture to be sent for when they could meet with a place to put it in. Many houses were closed altogether, owing to the death of the proprietors; and, in a great number of instances, the tradesmen who remained had sent away their families so that in less than six days from the commencement of the outbreak, the most afflicted streets were deserted by more than three-quarters of their inhabitants.
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> There were a few cases of cholera in the neighbourhood of Broad Street, Golden Square, in the latter part of August; and the so-called outbreak which commenced in the night between the 31st August and the 1st September, was, as in all similar instances, only a violent increase of the malady. As soon as I became acquainted with the situation and extent of this irruption of cholera, I suspected some contamination of the water of

> the much-frequented street-pump in Broad Street, near the end of Cambridge Street; but on examining the water, on the evening of the 3rd September, I found so little impurity in it of an organic nature, that I hesitated to come to a conclusion. Further inquiry, however, showed me that there was no other circumstance or agent common to the circumscribed locality in which this sudden increase of cholera occurred, and not extending beyond it, except the water of the above mentioned pump.... (pp. 38–39)

Snow began his study by obtaining from the London General Register Office a list of the deaths from cholera in the area occurring each day. These figures showed a dramatic increase in cases on August 31, which he therefore identified as the starting date of the outbreak. He found 83 deaths that took place from August 31 to September 1 (see Table 1), and made a personal investigation of these cases.

> On proceeding to the spot, I found that nearly all the deaths had taken place within a short distance of the pump. There were only ten deaths in houses situated decidedly nearer to another street pump. In five of these cases the families of the deceased persons informed me that they always sent to the pump in Broad Street, as they preferred the water to that of the pump which was nearer. In three other cases, the deceased were children who went to school near the pump in Broad Street. Two of them were known to drink the water; and the parents of the third think it probable that it did so. The other two deaths, beyond the district which this pump supplies, represent only the amount of mortality from cholera that was occurring before the irruption took place.
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> With regard to the deaths occurring in the locality belonging to the pump, there were 61 instances in which I was informed that the deceased persons used to drink the pump-water from Broad Street, either constantly or occasionally. In six instances I could get no information, owing to the death or departure of everyone connected with the deceased individuals; and in six cases I was informed that the deceased persons did not drink the pump-water before their illness.... (pp. 39–40)

Who Drank the Pump Water?

For reasons of clarity we summarize the results of Snow's investigation of these 83 deaths in Table 1, which shows that there were deaths among people not known to have drunk water from the Broad Street pump. These deaths therefore are facts that seem to contradict Snow's hypothesis. A scientist faced with facts contradictory to a hypothesis has many alternatives, only one of which is to discard the hypothesis. Another alternative is to make a closer examination of these facts, to see whether in some plausible way they can be shown either not really to contradict the hypothesis or actually to support it. It occurred to Snow to look for ways *the individuals in question might have drunk the water without being aware of it.*

TABLE I
Results of Snow's Investigation

83 Deaths[a]					
73 Living near Broad Street pump			10 Not living near pump		
61 Known to have drunk pump water	6 Believed not to have drunk pump water	6 No information	5 In families sending to Broad St. pump for water	3 Children attending school near pump	2 No information

[a]Out of 83 individuals who had died of the disease, 69 were known definitely or could be assumed to have drunk the pump water, 6 were believed not to have drunk it, and for 8 there was no information.

> The additional facts that I have been able to ascertain are in accordance with those above related; and as regards the small number of those attacked, who were believed not to have drunk the water from Broad Street pump, it must be obvious that there are various ways in which the deceased persons may have taken it without the knowledge of their friends. The water was used for mixing with spirits in all the public houses around. It was used likewise at dining-rooms and coffee-shops. The keeper of a coffee-shop in the neighbourhood, which was frequented by mechanics, and where the pump-water was supplied at dinner time, informed me (on 6th September) that she was already aware of nine of her customers who were dead. The pump-water was also sold in various little shops, with a teaspoonful of effervescing powder in it, under the name of sherbet; and it may have been distributed in various other ways with which I am unacquainted. The pump was frequented much more than is usual, even for a London pump in a populous neighbourhood. (pp. 41–42)

Snow next gives two striking observations that confirm the role of the pump. There were two large groups of people living near the Broad Street pump who had very few cases of cholera: the inhabitants of a workhouse and the employees of a brewery.

Why Were the Workhouse and the Brewery Spared?

In the workhouse, which had its own water supply, only 5 out of 535 inmates died. If the death rate had been the same as in the surrounding neighborhood, over 100 would have died.

> There is a brewery in Broad Street, near to the pump, and on perceiving that no brewer's men were registered as having died of cholera, I called on Mr. Huggins, the proprietor. He informed me that there were about 70 workmen employed in the brewery, and that none of them had suffered

from cholera—at least in a severe form—only two having been indisposed, and that not seriously, at the time the disease prevailed. The men are allowed a certain quantity of malt liquor, and Mr. Huggins believes that they do not drink water at all; and he is quite certain that the *workmen never obtained water from the pump in the street. There is a deep well in the brewery,* in addition to the New River water.... (pp. 41–42)

The Pump Handle

On September 7, Snow met with the Board of Guardians of the parish and informed them of his evidence as to the role of the pump in the outbreak. On September 8, the handle of the pump was removed, but, as Snow notes, by this time the epidemic had subsided, perhaps because many inhabitants had fled the neighborhood. So the removal of the pump handle did not produce any dramatic effect on the number of new cases (Fig. 5).

Following the epidemic, the pump was opened and examined. No direct evidence of leakage from nearby privies was found, but Snow states his belief that it must have occurred, perhaps by seepage through the soil, as on microscopic examination "oval animalcules" were found,

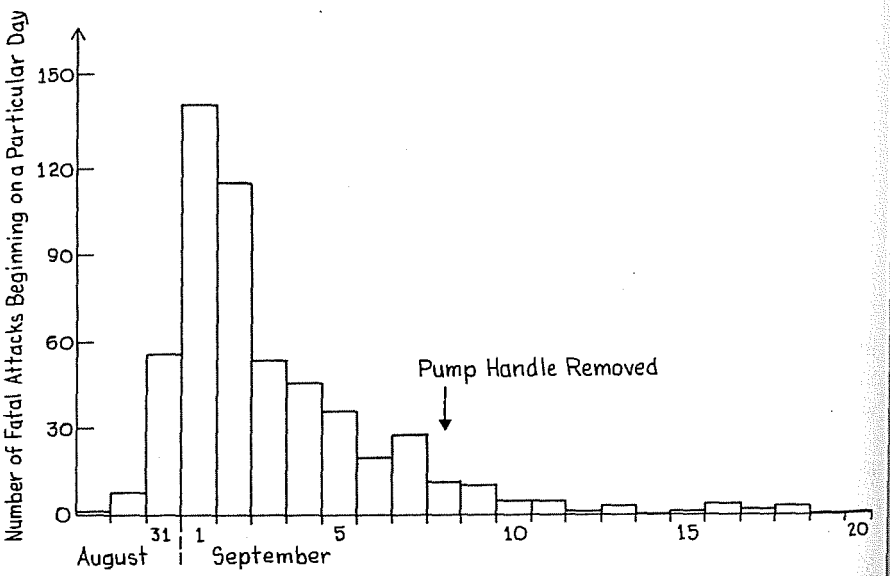

FIGURE 5. The Broad Street pump outbreak. The figure shows the number of fatal cases that began on a given date, plotted against the date. The arrow indicates when the pump handle was removed.

which Snow points out are evidence of organic contamination. (They were not the bacteria causing cholera, which were not detectable by the microscopic techniques of the time, nor did Snow take them seriously as a causative agent—rather, he knew that "animalcules" were very common in natural waters contaminated with sewage or other organic matter, even when no cholera was present.)

Additional evidence for the contamination of the pump water with sewage was provided by inhabitants of the neighborhood who had noticed a disagreeable taste in the water just prior to the outbreak and a tendency of the water to form a scum on the surface when it was left to stand a few days. Further, chemical tests showed the presence of large amounts of chlorides, consistent with contamination by sewage, but, like the animalcules, not constituting overwhelming proof. The question of chlorides in the drinking water will come up again more dramatically later on.

Snow's conclusion on the Broad Street pump outbreak is as follows:

> Whilst the presumed contamination of the water of the Broad Street pump with the evacuations of cholera patients affords an exact explanation of the fearful outbreak of cholera in St. James's parish, there is no other circumstance which offers any explanation at all, whatever hypothesis of the nature and cause of the malady be adopted. . . . (pp. 51–54)

THE SECOND EXPERIMENT: 1853–54

A Controlled Experiment—Where Did They Get Their Water?

The next section is the heart of Snow's monograph. It describes his observations during the 1853–54 outbreak and his performance of a controlled experiment to test his theory.

The basic idea of a controlled experiment is simple. Suppose mice could get cholera, and one wished to prove that water containing the excretions of cholera victims could produce the disease. One would take two large groups of mice similar in every relevant respect, put cholera excretions in the drinking water of one group (the test group), and leave them out of the water of the second group (the control group). If a large number of cholera cases were found in the test group and none in the control group, the case would have been made.

Human beings are more difficult to experiment on than mice. First, there is an ethical question—if you are inclined to believe that contaminated drinking water produces cholera, even though you are not yet

sure, do you have the right to let people drink it? Even if they would be drinking it anyway, don't you have an obligation to stop them?

The ethical problems can be avoided if by chance a "natural" experiment is available: it may happen that a group in the population has been exposed fortuitously to what is believed to be the cause of a disease. A controlled experiment is then possible if another group in the population can be found, similar in every relevant respect to the first one, except that it has not been exposed to the suspected cause. If the disease occurs in the first group and not the second, we have confirming evidence that the suspected cause really is the cause. But in such a "natural" situation it may be hard to prove the two groups similar in "every relevant respect."

For example, different districts of London had different water supplies and different cholera rates. But unfortunately, from the point of view of testing Snow's hypothesis that cholera is caused by contaminated water, the people in the different districts were different in other ways, also. The rich lived in different neighborhoods from the poor and suffered less from cholera. Was it because they had uncontaminated water supplies or because they ate better food, worked shorter hours at easier jobs, lived in newer, cleaner houses?

Also, different groups of equally "poor" people might differ in other significant ways. In London at that time there was a tendency for people of the same occupation to live in a single neighborhood, so that one neighborhood might have a lot of butchers, another might have tailors, and a third drivers of carts. Might susceptibility to cholera depend on occupation? Snow himself was aware that some occupational groups such as doctors were less likely to get cholera, and some, such as coal miners, were more likely. Perhaps some overlooked causative factor was related to one's work.

Since we now know that Snow's theory about the water supply was correct, we can feel that all these other differences are irrelevant and can be disregarded. But at the time this wasn't yet clear, and of course the purpose of the experiment was to find this out. If the control and test groups differed in three or four other ways besides getting their water supplies from a different source, we would not feel safe in blaming the water supply alone; any of these other differences between the groups might be responsible for the differences in cholera rates.

The Natural Experiment

It was Snow's genius to recognize the importance of the fortuitous circumstance that two different water companies supplied a single neighborhood in an intermingled way.

The two water companies in question both drew their water from the Thames, from spots that could be expected to be contaminated with the sewage of the city. But in 1852, after the epidemic during which Snow had done the experiments described above, one of these companies, the Lambeth Company, moved their waterworks upstream to a place free of London sewage. The other, the Southwark and Vauxhall Company, remained where it was. Both companies delivered drinking water to a single district of the city:

> The pipes of each Company go down all the streets, and into nearly all the courts and alleys. A few houses are supplied by one Company and a few by the other, according to the decision of the owner or occupier at that time when the Water Companies were in active competition. In many cases a single house has a supply different from that on either side. Each Company supplies both rich and poor, both large houses and small; *there is no difference either in the condition or occupation of the persons receiving the water of the different Companies.*

In the next sentence, Snow summarizes the basic idea of the experiment:

> As there is no difference whatever, either in the houses or the people receiving the supply of the two Water Companies, or in any of the physical conditions with which they are surrounded, it is obvious that no experiment could have been devised which would more thoroughly test the effect of water supply on the progress of cholera than this, which circumstances placed ready-made before the observer.
>
> 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, from gentlefolks down to the very poor, were divided into two groups without their choice, and, in most cases, without their knowledge; one group being supplied with water containing the sewage of London, and, amongst it, whatever might have come from the cholera patients, the other group having water quite free from such impurity.
>
> To turn this grand experiment to account, all that was required was to learn the supply of water to each individual house where a fatal attack of cholera might occur. I regret that, in the short days at the latter part of last year, I could not spare the time to make the inquiry; and, indeed, I was not fully aware, at that time, of the very intimate mixture of the supply of the two Water Companies, and the consequently important nature of the desired inquiry. (pp. 75–76)

Carrying out the idea required putting together two kinds of data: cholera cases and water supply. The first was easier to come by than the second.

> When the cholera returned to London in July of the present year, however, I resolved to spare no exertion which might be necessary to ascertain the exact effect of the water supply on the progress of the epidemic, in the places where all the circumstances were so happily adapted for the inquiry. I was desirous of making the investigation myself, in order that I

might have the most satisfactory proof of the truth or fallacy of the doctrine which I had been advocating for 5 years. I had no reason to doubt the correctness of the conclusions I had drawn from the great number of facts already in my possession, *but I felt that the circumstance of the cholera-poison passing down the sewers into a great river, and being distributed through miles of pipes, and yet producing its specific effects, was a fact of so startling a nature, and of so vast importance to the community, that it could not be too rigidly examined, or established on too firm a basis.* (p. 76)

Snow began to gather data on cholera deaths in the district. The very first results were supportive of his conjecture: of 44 deaths in the district in question, 38 occurred in houses supplied by the Southwark and Vauxhall Company.

As soon as I had ascertained these particulars I communicated them to Dr. Farr, who was much struck with the result, and at his suggestion the Registrars of all the south districts of London were requested to make a return of the water supply of the house in which the attack took place, in all cases of death from cholera. This order was to take place after the 26th August, and I resolved to carry my inquiry down to that date, so that the facts might be ascertained for the whole course of the epidemic. . . . (p. 77)

Chlorides and Receipts

Determining which water company supplied a given house was not always straightforward. Fortunately, Snow found a chemical test based on the fact that when a solution of silver nitrate is added to water containing chlorides a white cloud of insoluble silver chloride is formed. He found that the water from the two companies differed markedly in chloride content and thus could be easily distinguished.

The inquiry was necessarily attended with a good deal of trouble. There were very few instances in which I could at once get the information I required. Even when the water-rates are paid by the residents, they can seldom remember the name of the Water Company till they have looked for the receipt. In the case of working people who pay weekly rents, the rates are invariably paid by the landlord or his agent, who often lives at a distance, and the residents know nothing about the matter. It would, indeed, have been almost impossible for me to complete the inquiry, if I had not found that I could distinguish the water of the two companies with perfect certainty by a chemical test. The test I employed was found on the great difference in the chloride of sodium contained in the two kinds of water, at the time I made the inquiry. . . . (pp. 77–78)

[T]he difference in appearance on adding nitrate of silver to the two kinds of water was so great, that they could be at once distinguished without further trouble. Therefore when the resident could not give clear and conclusive evidence about the water Company, I obtained some of the water in a small phial, and wrote the address on the cover, when I could

examine it after coming home. The mere appearance of the water generally afforded a very good indication of its source, especially if it was observed as it came in, before it had entered the water-butt or cistern; and the time of its coming in also afforded some evidence of the kind of water, after I had ascertained the hours when the turncocks of both Companies visited any street. These points were, however, not relied on, except as corroborating more decisive proof, such as the chemical test, or the Company's receipt for the rates.... (p. 78)

It is worth noting how careful Snow was to be sure of the facts here—although he could guess the source of the water from its "mere appearance," he relied on more objective proof of its origin.

Deaths and Death Rates

Snow now expresses the result of his study in quantitative terms. He notes that the Southwark and Vauxhall Company supplied about 40,000 houses in London during 1853 and the Lambeth Company (drawing its water upstream) about 26,000. In the rest of London, where there were over 250,000 houses, there were *more* deaths than in the houses supplied by Southwark and Vauxhall—1422 compared with 1263—but there were 6 times as many houses, also. What matters here is not the total number of deaths, but the *rate* of deaths per house. Put another way, if you live in a house supplied by Southwark and Vauxhall, what are your chances of dying, compared with your chances if you live in a house supplied by another company? Snow expressed the rate in deaths per 10,000 houses, according to the following formula:

$$\text{Rate} = \frac{\text{deaths}}{\text{number of houses}} \times 10{,}000$$

The table gives the results:

The following is the proportion of deaths to 10,000 houses,* during the first seven weeks of the epidemic in the population supplied by the Southwark and Vauxhall Company, in that supplied by the Lambeth Company, and in the rest of London.

Table IX

	No. of houses	Deaths from Cholera	Deaths in each 10,000 houses
Southwark & Vauxhall Company	40,046	1263	315
Lambeth Company	26,107	98	37
Rest of London	256,423	1422	59

*Deaths per 10,000 houses.

> The mortality in the houses supplied by the Southwark and Vauxhall Company was therefore between eight and nine times as great as in the houses supplied by the Lambeth Company.... (p. 86)

BEING CRITICAL

Objections to Snow's Theory

Snow next considers an objection to his hypothesis: not everyone who drinks the polluted water gets sick. Note that he had used a similar objection against the "effluvia" hypothesis: not everyone exposed to the effluvia of cholera patients gets sick. However, he dealt differently with the two cases. He was able to find a relevant factor consistent with his own hypothesis to separate those who became ill from those who did not: they were members of different social groups with different sanitary practices that caused them to have different chances of ingesting excreta. On the other hand, Snow did not find, among those with equal chances of ingesting excreta, any factor that distinguished those who became ill from those who did not. Those who did not accept Snow's hypothesis, and had cited as evidence against it the fact that not all known to ingest excreta got the disease, would have been able to make a better case if they had been able to identify a factor distinguishing those who became ill from those who did not that was consistent with an alternative hypothesis.

Here is Snow's discussion of this problem:

> All the evidence proving the communication of cholera through the medium of water, confirms that with which I set out, of its communication in the crowded habitations of the poor, in coal-mines and other places, by the hands getting soiled with the evacuations of the patients, and by small quantities of these evacuations being swallowed with the food, as paint is swallowed by house painters of uncleanly habits, who contract lead-colic in this way.

Why Some Who Should Get Cholera Don't

> There are one or two objections to the mode of communication of cholera which I am endeavouring to establish, that deserve to be noticed. Messrs. Pearse and Marston state, in their account of the cases of cholera treated at the Newcastle Dispensary in 1853, that one of the dispensers drank by mistake some rice-water evacuation without any effect whatever. In rejoinder to this negative incident, it may be remarked, that several conditions may be requisite to the communication of cholera with which we are as yet unacquainted. Certain conditions we know to be requisite to the communication of other diseases. Syphilis we know is only communicable

in its primary stage, and vaccine lymph must be removed at a particular time to produce its proper effects. In the incident above mentioned, the large quantity of the evacuation taken might even prevent its action. It must be remembered that the effects of a morbid poison are never due to what first enters the system, but to the crop or progeny produced from this during a period of reproduction, termed the period of incubation; and if a whole sack of grain, or seed of any kind, were put into a hole in the ground, it is very doubtful whether any crop whatever would be produced.

An objection that has repeatedly been made to the propagation of cholera through the medium of water, is, that every one who drinks of the water ought to have the disease at once. This objection arises from mistaking the department of science to which the communication of cholera belongs, and looking on it as a question of chemistry, instead of one of natural history, as it undoubtedly is. It cannot be supposed that a morbid poison, which has the property, under suitable circumstances, of reproducing its kind, should be capable of being diluted indefinitely in water, like a chemical salt; and therefore it is not to be presumed that the cholera-poison would be equally diffused through every particle of the water. The eggs of the tape-worm must undoubtedly pass down the sewers into the Thames, but it by no means follows that everybody who drinks a glass of the water should swallow one of the eggs. As regards the morbid matter of cholera, many other circumstances, besides the quantity of it which is present in a river at different periods of the epidemic must influence the chances of its being swallowed, such as its remaining in a butt or other vessel till it is decomposed or devoured by animalcules, or its merely settling to the bottom and remaining there. In the case of the pump-well in Broad Street, Golden Square, if the cholera-poison was contained in the minute whitish flocculi visible on close inspection to the naked eye, some persons might drink of the water without taking any, as they soon settled to the bottom of the vessel.... (pp. 111–113)

In some respects Snow's defense against this objection would be accepted as valid today, in the light of knowledge gained in the century that has elapsed since the germ theory of disease was accepted. We know, for example, that individual susceptibilities to a given disease vary widely, often for reasons that even now are not well understood. Also, some individuals may suffer an attack of a disease in a mild and clinically unrecognized form and may subsequently be immune for a longer or shorter period of time. It is a very rare epidemic in which everyone gets sick.

Snow's explanation of why the individual who drank cholera evacuation by mistake did not contract the disease is not plausible today, nor can we believe that it would have been plausible at the time, especially to anyone skeptical of Snow's theory. It would have been more admirable, but less human, if Snow had acknowledged that this was one experimental fact he couldn't explain, and let it go at that.

Scotland Is Different

The next section discusses one oddity of the behavior of cholera: it was mainly a summer disease in England and would not spread in winter even when introduced then, but it seemed not to be seasonal in Scotland, running through its epidemic course as soon as it appeared, even in winter. Snow's explanation in terms of his theory is charming, and it shows the kinds of things a scientist has to be alert to.

It also may help to demolish a myth about the scientific method we have referred to in an earlier chapter: that scientific hypotheses are obtained by first examining the facts. In reality, the hypothesis comes first, and tells us which facts are worth examining. It is easy to see how Snow was led to compare the drinking habits of the English with those of the Scots, given his theory, but if one had only the facts about the seasonal differences in cholera between the two countries, would one have inferred a theory blaming the water supply?

In the Winter the English Drank Tea

> Each time when cholera has been introduced into England in the autumn, it has made but little progress, and has lingered rather than flourished during the winter and spring, to increase gradually during the following summer, reach its climax at the latter part of summer, and decline somewhat rapidly as the cool days of autumn set in. In most parts of Scotland, on the contrary, cholera has each time run through its course in the winter immediately following its introduction. I have now to offer what I consider an explanation, to a great extent, of these peculiarities in the progress of cholera. The English people, as a general rule, do not drink much unboiled water, except in warm weather. They generally take tea, coffee, malt liquor, or some other artificial beverage at their meals, and do not require to drink between meals, except when the weather is warm. In summer, however, a much greater quantity of drink is required, and it is much more usual to drink water at that season than in cold weather. Consequently, whilst the cholera is chiefly confined in winter to the crowded families of the poor, and to the mining population, who, as was before explained, eat each other's excrement at all times, it gains access as summer advances to the population of the towns, where there is a river which receives the sewers and supplies the drinking water at the same time; and, where pump-wells and other limited supplies of water happen to be contaminated with the contents of the drains and cesspools, there is a greater opportunity for the disease to spread at a time when unboiled water is more freely used.

While the Scots . . .

> In Scotland, on the other hand, unboiled water is somewhat freely used at all times to mix with spirits; I am told that when two or three people enter

a tavern in Scotland and ask for a gill of whiskey, a jug of water and tumbler-glasses are brought with it. Malt liquors are only consumed to a limited extent in Scotland, and when persons drink spirit without water, as they often do, it occasions thirst and obliges them to drink water afterwards. (pp. 117–118)

Other Theories: Effluvia, Elevation, Hard Water, and Soft Water

We have collected in one place Snow's discussion of alternate theories and his reasons for rejecting them. Giving fair consideration to theories opposed to one's own is something all scientists should try to do; but not all scientists are really capable of it, and are not necessarily bad scientists because of this shortcoming. Science proceeds by a consensus of scientists: one man's failure to be objective about a theory he doesn't like is made up for by the opposite bias of his opponents and the fairness of the less emotionally involved. Snow was better at it than most.

Whilst the presumed contamination of the water of the Broad Street pump with the evacuations of cholera patients affords an exact explanation of the fearful outbreak of cholera in St. James's parish, there is no other circumstance which offers any explanation at all, whatever hypothesis of the nature and cause of the malady be adopted.... Many of the non-medical public were disposed to attribute the outbreak of cholera to the supposed existence of a pit in which persons dying of the plague had been buried about two centuries ago; and, if the alleged plague-pit had been nearer to Broad Street, they would no doubt still cling to the idea. The situation of the supposed pit is, however, said to be Little Marlborough Street, just out of the area in which the chief mortality occurred. With regard to effluvia from the sewers passing into the streets and houses, that is a fault common to most parts of London and other towns. There is nothing peculiar in the sewers or drainage of the limited spot in which this outbreak occurred; and Saffron Hill and other localities, which suffer much more from ill odours, have been very lightly visited by cholera.... (pp. 54–55)

The low rate of mortality amongst medical men and undertakers is worthy of notice. If cholera were propagated by effluvia given off from the patient, or the dead body, as used to be the opinion of those who believed in its communicability; or, if it depended on effluvia lurking about what are by others called infected localities, in either case medical men and undertakers would be peculiarly liable to the disease; but, according to the principles explained in this treatise, there is no reason why these callings should particularly expose persons to the malady. (p. 122)

It is easy today to look down on the effluvia theory as so much unenlightened superstition. One should recognize, however, that the germ theory then was highly speculative and had very little evidence in its favor. The idea that disease could be spread by foul odors or other

poisonous emanations represented a great advance over views attributing disease to witchcraft or sin, and, in the absence of any knowledge of microorganisms, was a plausible explanation of contagion.

Further, the effluvia theory led to justified concern over the crowded and unsanitary living and working conditions of the poor. Interested readers should consult the report prepared for Parliament by E. Chadwick in 1842 for a description of these conditions.[3] Chadwick's report led to the first serious public health measures taken by the British government, and in fact these measures resulted in improved health of the population of England.

This illustrates a truism of scientific research: an incorrect theory is better than no theory at all, or, in the words of an English logician Augustus de Morgan, "Wrong hypotheses, rightly worked, have produced more useful results than unguided observation."[4]

Height above Sea Level

Dr. Farr's theory that cholera is less prevalent in a district the higher its elevation above sea level is treated differently from the effluvia theory by Snow. The latter he rejects completely, but Farr's theory had some validity at least within London. Snow shows that the limited correlation between the disease and elevation noted by Farr is actually better explained by his own theory: the low-lying districts of London are also those more likely to have water supplies contaminated by sewage.

Farr's observations can be thought of as a controlled experiment, the control and test groups being inhabitants of London living at different elevations above sea level. Indeed, the people living at the lower elevations suffered more cholera, but the two groups differed, as pointed out by Snow, in other significant ways, even though elevation was directly connected to the differences in the significant factor.

> Dr. Farr discovered a remarkable coincidence between the mortality from cholera in the different districts of London in 1849, and the elevation of the ground; the connection being of an inverse kind, the higher districts suffering least, and the lowest suffering most from this malady. Dr. Farr was inclined to think that the level of the soil had some direct influence over the prevalence of cholera, but the fact of the most elevated towns in this kingdom, as Wolverhampton, Dowlais, Merthyr Tydvil, and Newcastle-upon-Tyne, having suffered excessively from this disease on several occasions, is opposed to this view, as is also the circumstance of Bethlehem Hospital, the Queen's Prison, Horsemonger Lane Gaol, and several other large buildings, which are supplied with water from deep wells on the premises, having nearly or altogether escaped cholera, though situated on a very low level, and surrounded by the disease. The fact of Brixton, at an

> elevation 56 feet above Trinity high-water mark, having suffered a mortality of 55 in 10,000, whilst many districts on the north of the Thames, at less than half the elevation, did not suffer one-third as much, also points to the same conclusion.
>
> I expressed the opinion in 1849, that the increased prevalence of cholera in the low-lying districts of London depended entirely on the greater contamination of the water in these districts, and the comparative immunity from this disease of the population receiving the improved water from Thames Ditton, during the epidemics of last year and the present, as shown in the previous pages, entirely confirms this view of the subject; for the great bulk of this population live in the lowest districts of the metropolis.... (pp. 97–98)

Limestone and Sandstone

Another hypothesis, which agreed with at least some of the experimental facts, was proposed by John Lea of Cincinnati. Lea had found that districts in which the underlying rock formations were limestone had much more cholera than districts overlying sandstone. He conjectured that the calcium and magnesium salts, which were present in water in limestone districts, were somehow necessary for the cholera "poison" to have its effect. He noted as supporting evidence for this hypothesis the fact that towns that relied on river water, in which there was much calcium and magnesium, suffered more than towns that used rain water.

Snow's criticisms of Lea's hypothesis is in part specious. He attributed the difference in cholera rates between sandstone and limestone districts observed by Lea to a greater oxidizing power of sandstone on organic substances. This explanation is not very plausible, as Snow himself was aware—he had no evidence that limestone might not be equally oxidizing. We can be even more sure today that the correlation between cholera and rock formation found by Lea was entirely fortuitous. Snow of course explained the higher cholera rates in towns using river water on the greater likelihood that river water is contaminated with sewage.

APPLICATIONS TO OTHER PROBLEMS

What About Other Diseases?

Having established convincingly that cholera can be communicated through the water supply, Snow then extends his theory beyond its original area of applicability: is it possible that other infectious diseases are also transmitted in the same way? He considers four other epidemic

diseases: yellow fever, malaria (intermittent fever, ague), dysentery, and typhoid fever. He was wrong about the first two and right about the second two. His reasoning in the cases where he is wrong is interesting to quote, because he makes a plausible case:

> Yellow fever, which has been clearly proved by Dr. M'William and others to be a communicable disease, resembles cholera and the plague in flourishing best, as a general rule, on low alluvial soil, and also in spreading greatly where there is a want of personal cleanliness. This disease has more than once appeared in ships sailing up the river Plate, before they have had any communication with the shore. The most probable cause of this circumstance is, that the fresh water of this river, taken up from alongside the ship, contained the evacuations of patients with yellow fever in La Plata or other towns.... (p. 127)

> Intermittent fevers are so fixed to particular places that they have deservedly obtained the name of endemics. They spread occasionally, however, much beyond their ordinary localities, and become epidemic. Intermittent fevers are undoubtedly often connected with a marshy state of the soil; for draining the land frequently causes their disappearance. They sometimes, however, exist as endemics, where there is no marshy land or stagnant water within scores of miles. Towards the end of the seventeenth century, intermittent fevers were, for the first time, attributed by Lancisi to noxious effluvia arising from marshes. These supposed effluvia, or marsh miasmata, as they were afterwards called, were thought to arise from decomposing vegetable and animal matter; but, as intermittent fevers have prevailed in many places where there was no decomposing vegetable or animal matter, this opinion has been given up in a great measure; still the belief in miasmata or malaria* of some kind, as a cause of intermittents, is very general. It must be acknowledged, however, that there is no direct proof of the existence of malaria or miasmata, much less of their nature.
>
> That preventive of ague, draining the land, must effect the water of a district quite as much as it affects the air, and there is direct evidence to prove that intermittent fever has, at all events in some cases, been caused by drinking the water of marshes. (pp. 129–130)

In the following paragraph, Snow, to explain the apparent absence of direct person-to-person contagion in malaria, makes an inspired guess: the malaria parasite, he speculates, must spend part of its life cycle outside the human body. Indeed it does, in the body of the *Anopheles* mosquito.

> The communication of ague from person to person has not been observed, and supposing this disease to be communicable, it may be so only indirectly, for the materies morbi eliminated from one patient may require to undergo a process of development or procreation out of the body before it

*The word malaria as used by Snow is not the name of the disease but a term meaning "bad air."

enters another patient, like certain flukes infesting some of the lower animals, and procreating by alternate generations. (p. 133)

Snow's explanation of why yellow fever breaks out on ships arriving on the River Plate before they even land is quite plausible, but is of course wrong. Similarly, the close identification of malaria with marshes had been known since the time of Hippocrates, and Snow's conjecture that it comes from drinking marsh water is also plausible but wrong. It is interesting that the Italian physician Lancisi (1654–1720), whose "effluvia" theory of malaria is quoted by Snow, also suggested that mosquitoes might spread malaria.[5] Snow does not refer to this idea, and we do not know what he thought of it.

What to Do? Measures to Prevent the Spread of Cholera

The last part of Snow's monograph gives his list of recommended measures for preventing the spread of cholera. His ideas did not win immediate acceptance from his medical contemporaries, who felt that he had made a good case for some influence of polluted water in cholera but continued to believe in "effluvia" theories as an alternate or contributing cause for a while. In any event, his recommendations on the water supply were adopted, and London was spared any further cholera epidemics.

The measures which are required for the prevention of cholera, and all diseases which are communicated in the same way as cholera, are of a very simple kind. They may be divided into those which may be carried out in the presence of an epidemic, and those which, as they require time, should be taken beforehand.

The measures which should be adopted during the presence of cholera may be enumerated as follows:

1st. The strictest cleanliness should be observed by those about the sick. There should be a hand-basin, water, and towel, in every room where there is a cholera patient, and care should be taken that they are frequently used by the nurse and other attendants, more particularly before touching any food.

2nd. The soiled bed linen and body linen of the patient should be immersed in water as soon as they are removed, until such time as they can be washed, lest the evacuations should become dry, and be wafted about as a fine dust. Articles of bedding and clothing which cannot be washed, should be exposed for some time to a temperature of 212° or upwards.

3rd. Care should be taken that the water employed for drinking and preparing food (whether it come from a pump-well, or be conveyed in pipes) is not contaminated with the contents of cesspools, house-drains, or sewers; or, in the event that water free from suspicion cannot be obtained, it should be well boiled, and if possible, also filtered....

4th. When cholera prevails very much in the neighbourhood, all the provisions which are brought into the house should be well washed with clean water and exposed to a temperature of 212°F.; or at least they should undergo one of these processes, and be purified either by water or by fire. By being careful to wash the hands, and taking due precautions with regard to food, I consider that a person may spend his time amongst cholera patients without exposing himself to any danger.

5th. When a case of cholera or other communicable disease appears among persons living in a crowded room, the healthy should be removed to another apartment, where it is practicable, leaving only those who are useful to wait on the sick.

6th. As it would be impossible to clean out coal-pits, and establish privies and lavatories in them, or even to provide the means of eating a meal with anything like common decency, the time of working should be divided into periods of four hours instead of eight, so that the pitmen might go home to their meals, and be prevented from taking food into the mines.

7th. The communicability of cholera ought not to be disguised from the people, under the idea that the knowledge of it would cause a panic, or occasion the sick to be deserted.

The measures which can be taken beforehand to provide against cholera and other epidemic diseases, which are communicated in a similar way, are:

8th. To effect good and perfect drainage.

9th. To provide an ample supply of water quite free from contamination with the contents of sewers, cesspools, and house-drains, or the refuse of people who navigate the rivers.

10th. To provide model lodging-houses for the vagrant class, and sufficient house room for the poor generally....

11th. To inculcate habits of personal and domestic cleanliness among the people everywhere.

12th. Some attention should be undoubtedly directed to persons, and especially ships, arriving from infected places, in order to segregate the sick from the healthy. In the instance of cholera, the supervision would generally not require to be of long duration....

I feel confident, however, that by attending to the above-mentioned precautions, which I consider to be based on a correct knowledge of the cause of cholera, this disease may be rendered extremely rare, if indeed it may not be altogether banished from civilized countries. And the diminution of mortality ought not to stop with cholera.... (pp. 133–137)

What Snow Overlooked

Snow's monograph ends with a paragraph stating that typhoid fever, which killed many more in England than did cholera, may also be controlled by the measures he proposed. This was right, and both diseases were soon brought under control.

We would like to close Snow's story with one more quotation, be-

cause it tells us something important about one aspect of scientific research. In order to make the problems we want to solve tractable, we need to limit the range of what we study. Yet by doing so we risk overlooking important possibilities not included within the narrowed scope of our inquiry.

Early in the monograph, Snow gives his reasons for believing that the "morbid matter" causing cholera reaches the digestive tract directly by ingestion, rather than through a preliminary systemic infection.

> If any further proof were wanting than those above stated, that all the symptoms attending cholera, except those connected with the alimentary canal, depend simply on the physical alteration of the blood, and not on any cholera poison circulating in the system, it would only be necessary to allude to the effects of a weak saline solution injected into the veins in the stage of collapse. The shrunken skin becomes filled out, and loses its coldness and lividity; the countenance assumes a natural aspect; the patient is able to sit up, and for a time seems well. If the symptoms were caused by a poison circulating in the blood, and depressing the action of the heart, it is impossible that they should thus be suspended by an injection of warm water, holding a little carbonate of soda in solution.... (p. 13)

Today it is recognized that cholera kills by dehydration and that if victims receive sufficient fluid either orally or intravenously the disease is rarely fatal. It is ironic that it should not have occurred to Snow that the observation he reported suggests a way of treating the disease. But Snow was not looking for a treatment of cholera, he was trying to establish how it is transmitted, and in that he succeeded.

The Epidemiology of Cancer

In many ways Snow's approach to his problem may seem old-fashioned now. We have the advantage of the germ theory of disease, the benefits of more than a century of research into the behavior and life cycles of bacteria and other infective organisms, powerful microscopes and other laboratory apparatus to search for and identify them, knowledge of virus diseases, and statistics, a highly developed branch of mathematics, to help us analyze our experiments.

But the basic process by which Snow made his discovery—the recognition of a problem, the formation of a hypothesis, the design of an experiment to test that hypothesis, the critical evaluation of the results of that experiment, the consideration of alternative hypotheses—are the processes of all scientific research. They are as applicable to other fields of science as they are to the study of epidemics of contagious diseases, and as applicable in medical research today as they were in Snow's time.

The specific approach used by Snow—the search for the causes of diseases or clues to their origins by comparison of the naturally occurring distribution of diseases in different populations—forms a branch of medical research known as epidemiology. Although historically, as the name suggests, it began as a means of studying epidemics, the methods are applicable to a great variety of diseases or conditions, contagious or otherwise. For example, the identification of pellagra as a disease of nutritional deficiency by Joseph Goldberger in 1915 was made by just such an analysis as Snow's.[6] In Chapter 5 we will discuss attempts to understand the causes of mental disorders by similar methods. In the remainder of this chapter we will discuss briefly the application of epidemiological methods to a current and still unsolved problem, that of cancer, a major cause of death and disability. We do so partly for its intrinsic interest and partly to demonstrate some things about the interdependence of different fields of science.

Cancer is a disease characterized by the wild and uncontrolled proliferation of abnormal cells produced by the body. The biology and chemistry of this process have been studied for several decades, and extensive research is being carried out today. Some of the questions asked are: What are the factors that produce the abnormal cell in the first place? How does the abnormal cell differ from the normal cells of the body in its metabolism? Why do abnormal cells multiply so rapidly? Can their behavior be related to the molecular processes taking place within the cell in terms of the proteins present or of the nucleic acids which are the carriers of the genetic heritage of the cell? If these can be answered, perhaps some knowledge of the cause of cancer will be obtained that will suggest ways to prevent or treat it.

In contrast to these attempts to explain cancer in terms of the biological and biochemical functioning of normal and abnormal cells, the epidemiologist studies the distribution of cancer among populations. If differences in the cancer rates in different populations can be found, clues to the cause may emerge. Such differences may reflect differences in life-style and habits, genetic differences, or different exposures to certain environmental factors. In recent years evidence has been accumulating that the last factor is especially important: that certain types of cancer occur only if the victim has been exposed to some specific environmental hazard. The earliest such observation was that of Dr. Percivall Pott of London in 1775, who found cancer of the scrotum common in chimney sweeps and almost unknown in other men.[7] A more recent example is the observation that a form of lung cancer, mesothelioma, rarely observed in the general population, is quite com-

mon among men who have been employed for many years in the asbestos industry.

Cancer and Smoking[8, 9, 10]

Since about 1920 there has been a dramatic increase in the rate of epidermoid carcinoma of the lung in men. This also corresponds with a great increase in cigarette smoking in men. Is the cigarette smoking the cause of the increase in lung cancer? What additional evidence can be cited that either supports this hypothesis or makes it less likely? Are there alternative hypotheses that can explain the data better?

For example, while both cigarette smoking and lung cancer have increased dramatically in recent years, we could not maintain a causal relation unless those individuals who smoke more are the ones more likely to get lung cancer. People who are known to smoke heavily are indeed more likely to develop lung cancer, but a small number of victims have never smoked. Therefore, we cannot continue to maintain that smoking is the sole cause of the disease, but the hypothesis that it is a major cause is still tenable.

Even though it has been established that smokers are much more likely to get lung cancer than nonsmokers are, this may not necessarily imply a causal relation. People who smoke may differ from people who do not smoke in ways other than smoking. In fact, smokers drink more alcohol and coffee than do nonsmokers. Fortunately, not every smoker drinks a lot of these beverages, and some nonsmokers do. Controlled experiments have shown that neither coffee nor alcohol is associated directly with an increased risk of lung cancer.

Another factor of difference between smokers and nonsmokers is that on the average people who live in cities smoke more than people who live in rural areas. Again, it could be that there is something in the city environment that causes lung cancer, and the correlation with smoking is only a coincidence. Here the problem is more complicated. Comparison of urban–rural differences in lung cancer shows that city-dwelling nonsmokers *are* more likely to get lung cancer than rural nonsmokers, but the differences in rates are small compared to the differences in rates associated with smoking habits.

Further confirmatory evidence comes from the recent rising rate of lung cancer among women, together with the knowledge that women have also begun to smoke cigarettes heavily, the fact that risk of lung cancer among cigarette smokers is greater the more cigarettes they smoke, and the fact that among people who give up smoking the risk of

lung cancer decreases in proportion to the time elapsed since they stopped.

Nonepidemiological Evidence

Most scientists familiar with the epidemiological evidence for the hypothesis that cigarette smoking causes lung cancer find it fairly convincing, but it would be much more convincing if the precise biological mechanism by which the cancer is produced could be known. There are some scientists who use the word "proof" in this connection—who feel that only when a biological mechanism has been established can the causal relation be considered proven. In their view the high degree of correlation of smoking with lung cancer does not constitute proof. The position we take in this book is that no scientific hypotheses are "provable" if the word implies the certainty of mathematical proof. Hypotheses, however, can differ enormously in the subjective degree of confidence we have in them. We prefer to put the matter this way: knowledge of a biological mechanism greatly increases our confidence in a hypothesis about disease that was originally established as plausible by epidemiological methods. As convincing as Snow's hypothesis was, it became more so with the germ theory of disease and the identification of the specific organism responsible for cholera. It is to be expected, therefore, that the smoking–lung cancer relation so far supported by epidemiological evidence would seem even more probable if a biological basis could be established. Indeed, there is already some confirmatory evidence of this kind.

Clinical examination of the lungs and bronchial tissue of heavy smokers who do not have lung cancer shows changes that are considered precancerous. Similar changes have been produced in the bronchial tissues of dogs exposed to tobacco smoke. Tobacco smoke condensate painted on the skin of mice and other animals produces skin cancers. Chemical analysis of tobacco smoke reveals that it contains a number of chemicals known individually to produce cancer in laboratory animals.

Unsolved Problems

It must be conceded that there are many unanswered questions. While the hypothesis that cigarette smoking is a direct cause of lung cancer is a highly probable one, it would be even more so if answers to these questions could be found.

For example, what is the precise mechanism by which lung cancer is produced? Is it the action of one of the known chemical carcinogens in tobacco smoke? Is it several of them acting cooperatively? Is it some

other constituent of tobacco smoke not yet identified as a carcinogen? Some scientists have speculated, for example, that traces of certain radioactive elements known to be present in tobacco smoke also might be responsible. Others have blamed constituents of the cigarette paper. Smoking has been shown to damage the body's mechanism for removing foreign particles deposited on the surfaces of the lung. It has been proposed that dust particles bearing cancer-causing substances, that all of us are exposed to, are retained by the lungs of smokers for longer periods of time and thus have a greater chance of producing the disease.

Nonsmokers also get lung cancer, although their chances are much less. Why do they? Not all heavy smokers do get it—the majority, in fact, do not. How do they avoid it?

Conclusions reached by epidemiological studies often depend on biological or biochemical research before they are considered to be firmly established. However, the traffic is not all one way. Epidemiology in turn suggests lines of research for biologists and biochemists to follow. This has been the case with cancer research, where the identification, by epidemiological methods, of substances in the environment that are associated with a high risk of cancer has led to their study in the laboratory. It has also been the case in other fields of medical research. For example, in the discovery of vitamins, the relation between certain diseases and the absence of certain foods from the diet was first established epidemiologically, and only then could the search for the specific disease-preventing substances in foods and their chemical identification be undertaken.

The Cancer Atlas

Epidemiologists of the U.S. National Cancer Institute have published data on differences in cancer rates for over 30 different kinds of cancer in different counties of the United States.[11, 12] They have presented their results in tables and maps showing which counties have high, average, or low incidences of each kind of cancer. These maps show clearly whether a particular type of cancer is distributed uniformly over the country or is concentrated in certain areas (Figure 6).

For example, most types of cancer are more common in urban areas than in rural ones. Some kinds such as rectal cancer are more common among the well-to-do than among the poor; others such as cancer of the uterine cervix are more common among the poor. Melanoma, a type of skin cancer, is much more common in the southeastern part of the United States; it is believed to be related to overexposure to intense sunlight. In counties with high concentrations of chemical industries

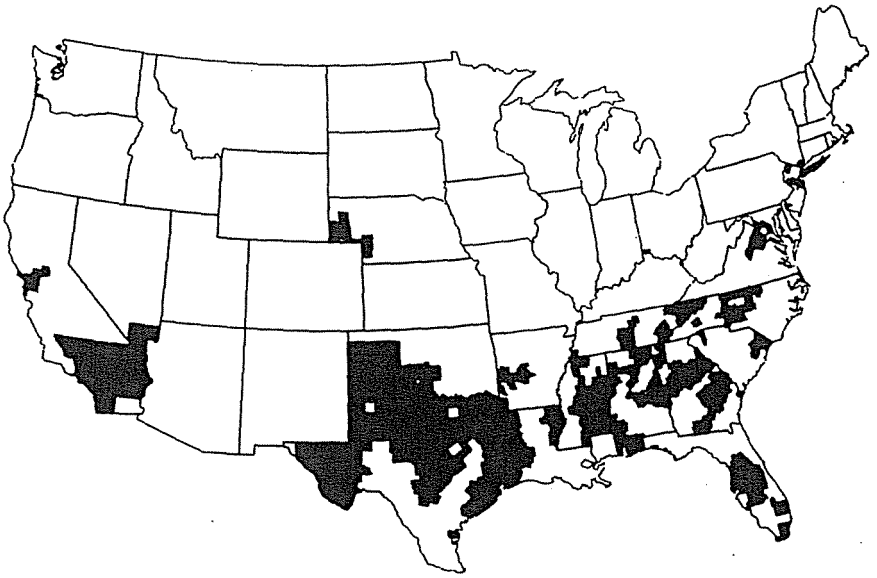

FIGURE 6. Distribution of melanoma (a form of skin cancer) among white males in the United States. The black areas show counties in which the rates are above the national average. (From T. J. Mason *et al.*, *Atlas of Cancer Mortality for U.S. Counties 1950–1969.* Reproduced with the permission of the U.S. Department of Health, Education, and Welfare.)

there is excessive mortality among men from cancers of the bladder, lung, and liver. Stomach cancer shows a complicated pattern: it is high in major cities, but also unusually high in certain rural areas of the Midwest where people of Russian, Austrian, Scandinavian, and German descent live. The countries these people immigrated from are known to have high rates of stomach cancer.

From Country to Country

The correlations described above are suggestive, but the patterns are quite complicated. The rates of different cancers do vary greatly from one part of the country to another, but are quite different for different forms of the disease.[11] When comparisons are made not just between different counties of the United States but between different countries of the world, the differences in rates are even more striking, and more puzzling as well.[13] Why should men in Bombay, India, have the world's highest incidence of cancers of the tongue, pharynx, and larynx and the

world's lowest incidence of cancers of the bladder and liver? Why should cancer of the liver in men be almost 100 times more common in Bulawayo, Africa, than in Bombay? It is obvious that no one single "cause" of cancer will emerge from these figures; each kind of cancer presents a problem of its own. This is a disappointing result, but the extraordinary differences in rates do permit us to draw one significant conclusion.

There are two obvious factors that differ from place to place in the world as well as within the United States that might account for the extraordinary differences in rates. The different peoples of the world may differ genetically in their susceptibility to cancer, or they may differ in their exposure to various environmental factors: diet, pollution, vegetation, viral diseases, and so on.

Evidence against genetic differences being a major factor in differences in cancer rates comes from studies of migrations. Breast cancer is much rarer and stomach cancer much more common in Japan than in the United States. (The Japan/U.S. relative rates are 1/6 for breast cancer and 6/1 for stomach cancer.[14]) That this might be a result of a genetic difference between Japanese and Caucasians is unlikely because the children and grandchildren of Japanese immigrants to the United States, who adopt the American life-style in diet, occupation, and general environment, get breast and stomach cancer at U.S. rates rather than Japanese rates. The explanation of these differences is not yet known; one factor being considered is differences in diet, but no convincing evidence has been obtained.

Making Hypotheses

If the wide geographic differences in cancer rates are reflections of environmental factors, then the discovery of which environmental factors are responsible and their elimination could reduce cancer rates in all countries to the lowest rates found in any one country. We are just beginning to explore this possibility, but little has been accomplished so far.

It is obvious to even a casual observer that the lives people lead in Bulawayo are different from those lived in Bombay, and both are unlike those lived in Europe or the United States. But which of the enormous number of differences among these places may be relevant to the cancer differences is not at all obvious. Good hypotheses do not come automatically from the gathering of facts. To find specific hypotheses to explain the different rates of each type of cancer—lip, lung, breast, pancreas, and so on—new and imaginative insights are needed.

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