Choosing a Future for Epidemiology: I. Eras and Paradigms

ABSTRACT

To inform choices about the future of epidemiology, the present condition of epidemiology is examined, in terms of its evolution through three eras, each demarcated by its own paradigm: (1) the era of *sanitary statistics* with its paradigm, *miasma*; (2) the era of *infectious disease epidemiology* with its paradigm, the *germ theory;* and (3) the era of *chronic disease epidemiology* with its paradigm, the *black box.* The historical context in which these eras arose is briefly described. In each era, the public health was at the center of the concerns of the founders and early protagonists of the prevailing paradigm. Around this intellectual development we weave a further theme. We argue that in the present era, the public health has become less central a concern. At the same time, in epidemiology today the dominant black box paradigm is of declining utility and is likely soon to be superseded. (*Am J Public Health.* 1996;86:668–673)

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Introduction

The present era of epidemiology is coming to a close. The focus on risk factors at the individual level—the hallmark of this era—will no longer serve. We need to be concerned equally with causal pathways at the societal level and with pathogenesis and causality at the molecular level.[1]

This paper prepares the groundwork for the argument that choices have to be made about the future of epidemiology. To look forward, we do well to look backward for guidance. Part I of this article sketches in brief outline the evolution of modern epidemiology in three successive eras. Following Kuhn,[2] we set the bounds of these eras in terms of dominant paradigms.[3] In Part II of this article, we advocate a paradigm for a fourth emergent era of "eco-epidemiology."

The Evolution of Modern Epidemiology

The underlying idea that marked the beginnings of quantitative epidemiology in the 17th century was concern for the public health and disparities in mortality across society. John Graunt the haberdasher, in his book *Natural and Political Observations Made upon the Bills of Mortality* (1662),[4] reported on the social distribution of death in London and especially on the mortal consequences of plague. In his book *Political Arithmetick* (1667),[5] the physician William Petty, Graunt's friend and sponsor in the Royal Society, was the first to provide a method to quantify the costs of mortality.

The utilitarian approach that Graunt, Petty, and others adopted was entirely in accord with the justifications prevailing over the beginnings of modern science in the 15th and 16th centuries. Driven by the twin forces of capitalism and the Protestant ethic, science was sanctioned (in Robert Merton's words)[6] by "economic utility" and "the glorification of God." This ideology fostered discoveries with immediate technical application in astronomy, navigation, firearms, optics, and many other fields.

With the accelerating flow of discovery over the centuries, science as an institution abandoned its utilitarian roots to become an end in itself. For some time, however, that was not true for epidemiology. That field retained a central concern with the public health and its social distribution.

Thus, in the face of the miseries of 19th-century England—the advance guard of industrialization and rapid urbanization—modern epidemiology gradually took shape and then burst into activity with the Sanitary Movement.[7–9] Thereafter, one can discern at least three eras in epidemiology, each with its own dominant paradigm: (1) the era of *sanitary statistics* with its paradigm, *miasma;* (2) the era of *infectious disease epidemiology* with its paradigm, the *germ theory;* and (3) the era of *chronic disease epidemiology* with its

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See related editorial by Winkelstein (p 621) and comment by Koopman (p 630) in this issue.

TABLE 1—Three Eras in the Evolution of Modern Epidemiology

Era	Paradigm	Analytic Approach	Preventive Approach
Sanitary statistics (first half of 19th century)	Miasma: poisoning by foul emanations from soil, air, and water	Demonstrate clustering of morbidity and mortality	Drainage, sewage, sanitation
Infectious disease epidemiology (late 19th century through first half of 20th century)	Germ theory: single agents relate one to one to specific diseases	Laboratory isolation and culture from disease sites, experimental transmission, and reproduction of lesions	Interrupt transmission (vaccines, isolation of the affected through quarantine and fever hospitals, and ultimately antibiotics)
Chronic disease epidemiology (latter half of 20th century)	Black box: exposure related to outcome without necessity for intervening factors or pathogenesis	Risk ratio of exposure to outcome at individual level in populations	Control risk factors by modifying lifestyle (diet, exercise, etc.) or agent (guns, food, etc.) or environment (pollution, passive smoking, etc.)

paradigm, the *black box.* Each of these eras is described in historical context below (Table 1).

Sanitary Statistics and Miasma

Miasma was the prevailing theory of the Sanitarians for the greater part of the 19th century. Sanitary statistics made plain the toll of sickness and death in the city slums of England, France, Germany, Scandinavia, and the United States (forerunners of the squatter camps, favelas, or barrios in today's less developed world). For the conditions in these slums, the Sanitarian hypothesis of miasma impugned poisoning by foul emanations from the soil, water, and environing air. The environmental causes were thought to have broad and multiple manifestations in morbidity and mortality, and the sanitary statistics that were collected as evidence were largely undifferentiated; that is, they were related more to overall morbidity and mortality than to specific diseases. Only in 1839 in England did William Farr begin to use specific diagnostic classifications for national mortality statistics.[10]

Closed drainage and sewage systems, supplemented by garbage collection, public baths, and housing, were the remedies that would disperse miasma, reduce mortality and morbidity (as indeed they did), and dispel the poverty of the new urban poor (as indeed they did not). A foremost proponent—and in some cases, the originator—of these innovations was Edwin Chadwick.[11] Chadwick was a reformist who argued that disease engendered by the physical environment caused poverty. Friedrich Engels, his contemporary, was a revolutionary who, in documenting the ills of Manchester factory workers, understood poverty to be the cause rather than the consequence of their ills.[12] But both agreed that the issues were societal and that the appropriate measures thus had to be applied across society.

To emphasize the underlying public health and social values of the sanitary pioneers, it is worth noting that statistics began literally as the study of the state and of the pertinent data. The newly formed London Statistical Society was chiefly concerned with assembling that data.[13] Louis René Villermé in France and William Farr in England,[10,14] founding figures of epidemiology as we know it today, are only two among many who worked to advance the public health in this fashion.

Epidemiologists, largely autodidacts, were often medical heroes in this era.[15,16] Young physicians were excited by the challenge of emergent patterns of disease that seemed rooted in a horrendous environment of urban misery. Beginning in 1858 John Simon, as chief medical officer of the national Board of Health in England, was able to draw around him over a few years a brilliant team—17 in all, no fewer than 8 of whom gained election to the Royal Society on the strength of their work. These epidemiologists mapped excess mortality across the country by district and in relation to housing, infant care, and specific diseases; studied a wide range of industries and occupations; detected many hazards from dusts, heavy metals, and general working conditions; and conducted national surveys of diet, parasite-infested meat, and food contamination.

Unfortunately, these high points of the era closely preceded its culmination. Unmodified, the miasma paradigm could not survive advances in microbiology, and its demise brought an end to the Sanitary Era. The tenacity of some of the brilliant figures of the movement, such as Edwin Chadwick and Florence Nightingale, in resisting revision of their theory rather than subsume the new biology invited ridicule from medical scientists that has hardly yet been dispelled, and the broad perspective for which they stood gradually faded. The drama of the new microbiology was not to be gainsaid.

An irony of the history of public health is that, while the sanitarians were mistaken in their causal theory of foul emanations, they nonetheless demonstrated how and where to conduct the search for causes in terms of the clustering of morbidity and mortality. The reforms they helped to achieve in drainage, sewage, water supplies, and sanitation generally brought major improvements in health. Their mistake lay in the specifics of biology rather than in the broad attribution of cause to environment.[17]

Infectious Disease Epidemiology and the Germ Theory

In 1840, Jakob Henle published a tightly argued treatise that hypothesized (as a few beginning with Fracastorius and others had done before him) that infection by minute organisms was a major cause of disease.[18–20] Despite John Snow's founding work of 1849 to 1854 in analytic epidemiology on the organismic cause of cholera[21] and his advances on Henle's formulation,[22] 25 years passed before Henle was vindicated. Louis Pasteur's demonstration of a living organism as the agent in an epidemic afflicting silkworms culminated in 1865.[23] Studies of infection and contagion in human disease—for instance, tuberculosis, anthrax, and leprosy[24–26]—followed. Finally, in 1882, Henle's one-time student Robert Koch established a mycobacterium as "the cause" of tuberculosis.[27] Henle, Snow, Pasteur, and

Koch can well stand as symbolic founding figures of the new era.

Snow and Koch faced directly the most acute public health problems of the time. Although Henle had no means of intervention at hand and Pasteur worked first on the commercial problems of diseases that threatened the silk industry and viticulture, they too declared and shared a public health perspective on the prevention of disease. Despite these origins, the new paradigm of disease that followed from their work, the *germ theory*, led in the end to the narrow laboratory perspective of a specific cause model[28]—namely, single agents relating one to one to specific diseases.

The germ theory and its attendant view of specific cause dominated medical and public health sciences from the last quarter of the 19th century through at least the mid-20th century. Single agents of disease were sought by the isolation and culture of microorganisms from disease sites, the experimental transmission of these microorganisms, and the reproduction of lesions. The appropriate responses were to limit transmission by vaccines, to isolate those affected, and, ultimately, to cure with chemotherapy and antibiotics. Laboratory-based diagnosis, immunization, and treatment gained precision with every new advance. The miasma theory was relegated to the same oblivion as phlogiston.

At the same time, the epidemiology of populations and environmental exposures, and the social dynamics of disease that had flowed from the miasma theory, went into decline, replaced by a focus on control of infectious agents. Epidemiology was often a derivative pursuit rather than a creative science in its own right. The new era scarcely maintained, let alone matched, the epidemiological advances of the 19th century in the design and conduct of field surveys, the construction of national statistical systems for vital data, and the statistical analyses of large numbers.[17] The adherents of the traditional philosophy of public health lost prestige and power in the medical hierarchy and, indeed, were disparaged in ways that in many places continue in the present.

The search for other than microbiological causes of disease in the environment stumbled if it did not altogether cease. Thus, in the United States, Joseph Goldberger, in his work on pellagra from 1914 through the 1920s,[29,30] ran against the tide of belief when he established nutritional deficiency as a cause of infection. This was even more the case when, in the rural South, he and Edgar Sydenstricker showed the dietary deficiency to be consequent on the poverty of sharecroppers and other workers trapped by the economic structure of the cotton fields.

In the same period, the search for a viral cause for the growing scourge of poliomyelitis was of course ultimately justified. But the concentration of resources in the laboratory search for an organism led to the neglect of key epidemiological findings and rendered futile the preventive approaches attempted. As early as 1905, Ivar Wickman in Sweden[31] and, a decade later, Wade Hampton Frost in the United States[32] had concluded from epidemiological data that widespread transmission of silent infection by some unknown agent was the underlying factor in the summer epidemics that were devastating the children of the better-off classes in particular.

The irony of the Sanitary Era was here reversed. While, within their limited frame of reference, the germ theorists were accurate in their causal attributions for many diseases, their narrow focus retarded the creative use of bacterial discoveries to advance the science of epidemiology. Some have argued that the decline of infectious diseases in the developed countries in the first part of this century, at the height of the germ theory paradigm, owed very little to science (including the use of vaccines and antibiotics) and much to nutrition or improved living standards.[33,34] While closer analysis does not sustain the argument against the role of science,[35] the primary role of economic development and social change is not in doubt.

Whatever the causes, the great scourges of communicable disease did come under control in the developed countries. Once the major infectious agents seemed all to have been identified and communicable disease no longer overwhelmed all other mortal disorders, the force of the germ theory paradigm faded. With notable exceptions such as René Dubos,[36] few anticipated the recrudescence of communicable disease or new global epidemics. With the emerging predominance of chronic disease of unknown cause, under any credible causal paradigm the social and physical environment had now to be reckoned with once more.

Chronic Disease Epidemiology and the Black Box

World War II serves as a convenient watershed for the beginning of the Chronic Disease Era and the black box paradigm. Shortly after the war ended in 1945, it was clear that, in the developed world, rising chronic disease mortality had overtaken mortality from infectious disease. The rise was not owed to the aging of populations alone. In middle-aged men specifically, the rises in peptic ulcer disease, coronary heart disease, and lung cancer were in each case fast and frightening enough to earn place and title as epidemics.[37]

By this time, also, chemotherapy and antibiotics had been added to the medical armamentarium. Their overwhelming therapeutic effects seemed to give tangible evidence that the major infectious diseases had been conquered. Only later was it discerned that these treatments were neither the only nor the primary factor in the steady decline of these diseases in the first half of the 20th century.[33]

The prevailing epidemiology of our day expressed the effort to understand and control the new chronic disease epidemics. Again the era was, at the outset, driven by public health concepts. The problems selected for investigation were the chronic diseases that most visibly threatened the public health, and the groups studied were those at manifest risk—namely, middle-aged men.

Chronic disease epidemiology took firm hold with the first undeniable successes in this endeavor. British epidemiologists Richard Doll, Austin Bradford Hill, Jeremy Morris, Thomas McKeown, and others were key figures. The case–control and cohort studies on smoking and lung cancer, and the early cohort studies on coronary heart disease that established serum cholesterol and smoking as risk factors, demonstrated the power of the observational method and established its credentials.[2]

These studies carried the invisible imprimatur of the black box paradigm ("black box" being the general metaphor for a self-contained unit whose inner processes are hidden from the viewer). This paradigm related exposure to outcome without any necessary obligation to interpolate either intervening factors or even pathogenesis (although not all neglected such interpolation). Epidemiologists were faced once more, as in the Sanitary Era, with major mortal diseases of completely unknown origin. At the outset, of necessity they resorted to straightforward descriptive studies of disease distribution and exploratory sweeps for possible factors that enhanced risk.[37] As they moved on to test the emergent observations, these epidemiologists relied upon ingenuity in design and the seizing of opportune circumstance to reach their conclusions. They seldom resorted to complex statistical analysis.

The studies of lung cancer were particularly influential in giving the new paradigm credibility. Pathogenesis was by-passed. Thus, the best biological support to be found for the smoking–lung cancer relationship was quite indirect, residing in the demonstration by the Kennaways and their colleagues that tars applied to the skin of mice were carcinogenic.[38] Indeed, for another 4 decades, no direct analogy with the epidemiological studies of smoking existed in animal experiments.

Step by step, the complexities of chronic disease epidemiology emerged, first in matters of design and causal inference and, in parallel a little later, in matters of statistical analysis.[2] The incipient thinking on design of previous decades was developed and systematized.[39,40] The structure of designs was clarified, the necessity for statistical power and the advantages of large numbers understood.[41]

Epidemiologists were obliged to depart from the specific-cause model of the germ theory. The metaphor of a "web of causation"[40] characterized the multicausal nature of public health problems, particularly those of chronic disease. After this beginning, one of us tried for his own part to give systematic form to the problems of inference that arose in the nascent epidemiology of a multivariate world.[17]

Later, analytic issues and statistical refinement became a driving force. The sharpening of technique led to a cycle of continual refinement. Epidemiologists began to explore in depth the subtleties of confounding, misclassification, survivorship, and other such issues. This labor is represented in the elegant and unifying concept of the fourfold table and the case–control and cohort designs as alternative methods of sampling the population disease experience to estimate risk ratios or odds ratios.[17,41–44]

The black box paradigm remains the prevailing model, and virtually all contemporary epidemiologists including ourselves have made use of it. It can still yield findings of public health significance. Neural tube defects provide a recent example. Typical black box approaches eventually led to the major discovery of the role of folate deficiency in neural tube defects. Early studies found variations with social class, geography and ethnicity, and economic cycles.[45] Further studies found exposure to famine early in pregnancy to be associated with an increased risk of congenital neural defects and prenatal vitamin intake to be associated with a decreased risk.[46,47] Finally, going beyond the black box, animal studies followed by clinical trials of supplementation established that periconceptional folic acid can prevent a large proportion of neural tube defects.[48,49]

Momentum for a New Era

The climax and, in all likelihood, the culmination of the black box as dominant paradigm is already upon us. Two forces, characteristic of our time and much written about, are blunting the black box paradigm: (1) a transformation in global health patterns and (2) new technology.

Health Patterns

With regard to health patterns, none has had more impact than the human immunodeficiency virus (HIV) epidemic. Although epidemiology has made some notable contributions to understanding the epidemic, black box epidemiology is ill equipped to address epidemic control. The causative organism as well as the critical risk factors are known, so prevention is theoretically possible. Yet the HIV epidemic has demonstrated that both developing and developed countries remain vulnerable to devastation by infectious disease.

Analysis of mass data at the individual level of organization alone, as implied by the black box paradigm, does not allow us to weigh at which points in the hierarchy of levels intervention is likely to be successful.[50,51] No vaccine now in prospect seems likely to achieve the efficacy level that could also achieve epidemic control. Absent such efficacy, the failure to control the disease resides in our lack of understanding of transmission and illness in the social context. We know which social behaviors need to change, but we know little about how to change them, even when entire societies are at stake.

In retrospect, our confidence during the Chronic Disease Era about the control of infectious diseases seems naive and also blind to the less developed world. For the majority of the world's population, chronic infections—tuberculosis, syphilis, malaria, and many others—were never under control. As with HIV infection, the immediate causes and the risk factors were known, but this knowledge could not be translated into protection of the public health.

Similarly, our confidence in our ability to control chronic noncommunicable diseases themselves by modifying behavior that carries risk has been shaken. Again, knowledge of risk factors and interventions directed solely at changing the behavior of individuals, even across several communities, have proven insufficient.[52,53]

Health problems driven by societal problems point to the location of the underlying difficulties. The black box paradigm alone does not elucidate societal forces or their relation to health. The focus on populations is generally directed at the individuals within them. Prevention at the societal level, conceptualized as intervening with individuals en masse, is often nullified when the target is a social entity with its own laws and dynamics.

Technology

With regard to technology, the developments that will drive research and that can lead epidemiology to a new paradigm reside primarily in biology and biomedical techniques on the one hand, and in information systems on the other. These advances have begun to reshape all health disciplines.

Biological techniques such as genetic recombination and imaging have transformed the ability of epidemiologists to comprehend human disease at the microlevel. For example, the methods of recombinant DNA have led to recognition of both viral and genetic components in insulin-dependent diabetes[54]; to the definitive tracking from person to person of HIV, tuberculosis, and other infections through the molecular specificity of the organisms[55]; to the discovery of a herpes virus as almost certainly the agent in Kaposi's sarcoma[56]; and to the drama of the familial tracking and marking of the first breast cancer gene.[57] Imaging has undermined the notion of schizophrenia as functional psychosis and given backing to the existence of environmental factors.[58] It has also allowed us to discover a frequency of brain lesions in the premature newborn that was unsuspectedly high overall and concentrated in the earliest hours of life.[59] Learning from the new technology has only begun. Once unimaginable possibilities follow from the mapping of the human genome for specifying the role of heredity in disease, and no less from the visualization of physiological processes for interpreting human function.

The potential contribution of these advances to epidemiology is an exquisite refinement of the definition and measurement of susceptibility, exposure, and outcome. Such refinement also clarifies the intervening pathways and so elucidates with precision causal processes and not merely causal factors. We can be confident that new techniques, properly applied, can help dig epidemiology out of the slough of marginally significant risk estimates.[60,61]

In parallel, technology at the societal level in the form of the global communication network has opened new possibilities for understanding and controlling disease. Information networks can provide instant access to—and enable the continuous assemblage of—existing stores of vital statistics and other relevant health and social data[62] across the world. Such data have myriad uses for newly empowering public health. They promise a capacity for devising and testing well-directed interventions at a societal level. Stores of data can be mined to describe distributions across societies, to make comparisons of strata and groups nationally and internationally, to generate and test hypotheses, and to serve as sampling frames. Continuous accumulation of data over time can serve for overall surveillance of health states, the detection of nascent epidemics and new diseases, the response to disasters, and the evaluation of interventions. This technology thus brings comprehension of large-scale phenomena and even systems within our grasp; it places at our command the ability and the necessity to recognize broad dynamic patterns and, not least, disease in its social context.

Conclusion

When research under the current black box paradigm in its pure form relies on risk ratios that relate exposure to outcome with no elaboration of intervening pathways, it forfeits the depth offered by our new biological knowledge. In addition, because of an implicit and sometimes explicit commitment to analyzing disease solely at the individual level, research under this paradigm also dispenses with the potential breadth offered by new information systems in placing exposure, outcome, and risk in societal context.

The apogee of the black box paradigm is heralded by epidemiology texts of the 1980s.[63,64] These mark two trends. They move away from the public health orientation of the pioneers of the Chronic Disease Era. At the same time, analysis edges out design as the central focus. At the extreme we find an epidemiology untrammeled by the call to address disease in social groups, communities, and other formations of the social structure. Thus, a widely used modern text endorses a pithy definition of epidemiology as the study of disease occurrence,[64(p17)] implicitly setting aside public health ends. Epidemiology in this view is akin to the physical sciences in sharing a search for the highest levels of abstraction in universal laws.[65] Research in this universalist vein cannot take advantage of the extraordinary shifts and opportunities opened by new dynamics of disease and new technology.

In the evolution of modern epidemiology, dominant paradigms have been displaced by new ones as health patterns and technologies have shifted. As happened with previous paradigms, the black box, strained beyond its limits, is soon likely to be subsumed if not superseded entirely by another paradigm. This paradigm reflects a particular era in our development as a discipline. In our view, we stand at the verge of a new era. □

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