

Developing an Integrated Epidemiologic Approach to Emerging Infectious Diseases

Stephen S. Morse¹ and James M. Hughes²

Epidemiology has been a major contributor to the success of the disease control efforts of the past century, culminating in such signal triumphs as the global eradication of smallpox and the eradication of polio from the Western Hemisphere. However, in recent years, partly because these very successes led to a pervasive optimism about infectious diseases in the future, there has been a waning interest in infectious disease epidemiology even though infectious diseases remain the leading cause of death worldwide and an important cause of death in the United States (1–3). In addition, the tragic recent explosion of the acquired immunodeficiency syndrome (AIDS) pandemic and the emergence of multiple drug resistant tuberculosis forcefully reminded us that infectious diseases could not be relegated to the past.

AIDS, like many of the plagues of the past, falls into the category of emerging infections, seemingly new diseases that appear suddenly and unexpectedly. Emerging infections can be defined as those that either have newly appeared in a population or that are rapidly increasing their incidence or expanding their geographic range (4, 5). Other recent examples include hantavirus pulmonary syndrome, Lyme disease, hemorrhagic colitis, and hemolytic uremic syndrome (resulting from a foodborne infection caused by certain strains of *Escherichia coli*), and Ebola hemorrhagic fever in Africa (6). Past scourges can also recur and are referred to as reemerging diseases, which are often conventionally understood and well recognized public health threats that have increased or reappeared because previously active public health measures have lapsed or sanitary infrastructure has deteriorated. Specific factors precipitating disease emergence can be identified in virtually all cases (2, 4, 5). These include

ecological or environmental factors that place people in increased contact with a pathogen or its natural host, and environmental, social, demographic, and behavioral factors that promote establishment and dissemination of a pathogen previously introduced into a smaller population.

The conditions of modern life and changes in human behaviors make these factors more prevalent, giving reason to expect emerging diseases to increase. Historically, "new" diseases have appeared and spread as by-products of exploration, trade, or warfare, when the movement of people, animals, or goods brought geographically isolated infections to new grounds (7). In the nineteenth century, steamships carried cholera to Europe and Africa. Today, trucks, freighters, and airplanes have largely replaced caravans and steamships, allowing even richer opportunities for infections to emerge and spread efficiently. Speed of travel and global reach of infections are borne out by studies modeling the spread of influenza epidemics (8) and of human immunodeficiency virus (HIV) (9, 10), as well as by the actual progress of known epidemics.

Other factors are also allowing emerging infections to appear at increasing rates and could facilitate wider and more rapid spread. In many parts of the world, economic conditions are encouraging the mass movement of workers from rural areas to cities. It has been estimated that, largely as a result of this migration, by the year 2025, 65 percent of the world population, including 61 percent of the population in developing regions, will live in cities (11). The phenomenon of rural to urban migration can allow infections arising in isolated rural areas, which may once have remained unrecognized and localized, to reach larger populations, with the city serving an amplifying function. An infection can become further disseminated when other migrants return home with an infection acquired in the city, a pattern now being observed with HIV in Asia.

The history of HIV, in fact, is a case in point. HIV may have originated as a zoonotic introduction in a place where people were in contact with the natural host (12). After its probable first move from a rural area into a city, HIV-1 spread along highways to other

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Abbreviations: AIDS, acquired immunodeficiency syndrome; HIV, human immunodeficiency virus.

¹Columbia University, School of Public Health, New York, NY.

²Director, National Center for Infectious Diseases, Centers for Disease Control and Prevention, Atlanta, GA.

Reprint requests to Dr. Stephen S. Morse, Division of Epidemiology, Columbia University School of Public Health, 600 West 168th Street (PH-18), New York, NY 10032.

regional cities, and later by long distance routes, notably by air travel, to distant places (13). In the future, other microbes are likely to benefit from similar opportunities. In industrialized countries, other high-density settings, such as day-care centers, prisons, and shelters for the homeless, can allow both common and new diseases to spread rapidly once they have gained a foothold.

Epidemics such as AIDS demonstrate the interplay of complex ecological, social, and behavioral factors. Controlling the infections of tomorrow will increasingly require understanding and assessing the roles of each of these factors in disease, and designing appropriate strategies that take them into account. Epidemiology must integrate approaches to studying the ecological, social, and behavioral context of disease into its own core subject matter. There have been epidemiologic traditions that have incorporated strong ecological underpinnings (14), and there are opportunities now to develop an integrated epidemiology that will further develop these approaches (15, 16). Human behavior, which is often a key factor in the appearance and spread of infections, must also be included in the equation. Many of the difficulties in dealing with the AIDS pandemic have stemmed precisely from our inability to deal effectively with these social factors that have allowed this virus to spread (17).

Being prepared for emerging infections will require strengthened surveillance and response capacity (18–20). Numerous expert analyses have called for the development of an effective global early warning and response system (18–22), while noting the perilous and fragmented state of our present systems (21). In all of this, epidemiology must play a central role. However, epidemiologists trained in infectious disease surveillance and control remain in short supply, with limited attention to the subject in both medical and public health curricula.

There is an equally critical need to integrate epidemiologic and laboratory surveillance functions. The availability of powerful new tools makes this an opportune time. Biotechnology continues to expand the power of laboratory-based surveillance and increases the feasibility of field applications worldwide. New analytic tools, including geographic modeling and electronic data collection and analysis, have similarly expanded capabilities that can be harnessed on the epidemiologic side, making it possible for the epidemiologist and laboratorian to share information. The next essential step is to integrate these elements at the front line, by fostering settings for infectious disease surveillance in which the specialties work closely together and learn to share data and vocabularies. At the same time, it is critically important to improve com-

munication and collaboration between clinicians and clinical microbiologists, who are often the first to recognize emerging and reemerging infections, and public health professionals with expertise in epidemiology and microbiology.

Molecular epidemiology is one promising product of the interaction between epidemiology and the laboratory (23, 24). As indicated by recent progress in applying molecular approaches to ecology (25), this interaction can even mutually reinforce the priority of integrating ecological, social, and behavioral sciences into epidemiology. Even with the appropriate structures in place, however, there are serious problems that must be overcome. In addition to trained personnel, now in short supply, a career path, requiring stable funding for these efforts, must also be assured. The recent responses to the outbreaks of plague in India and Ebola hemorrhagic fever in Zaire demonstrated how thin the resources are, both in terms of trained personnel and laboratory capacity. The international community was able to mount an adequate ad hoc response only by stretching available capabilities to the limit. In the case of plague, for example, the Centers for Disease Control and Prevention had the only functioning World Health Organization Collaborating Center for Plague, and this Center was staffed by only one full-time scientist. Assembling a team to assist with the international investigation in India required involvement of epidemiologists, microbiologists, and experts in rodent and vector control from different parts of the organization.

Effective surveillance will also require capturing the clinical data and recognizing the unusual. Ironically, while insurance companies have devised systems for collecting and sharing medical information for claims processing, there is no consistent way to access medical records electronically for medical or public health purposes (26). Therefore, clinicians and clinical microbiologists play a critically important role in recognizing and reporting such unusual diseases and syndromes.

The contributions in this volume analyze the epidemiology of important emerging and reemerging infections, such as malaria, tuberculosis, influenza, and Legionnaires' disease, and the impact of important host, social, and behavioral factors—migration, high-density settings in industrialized countries, high-intensity agriculture, and the growing population of immunosuppressed individuals now at increased risk for these infections. The essential role of the laboratory, and its constantly increasing power to identify previously unrecognized organisms, is discussed in the final contribution. The contributions in this volume demonstrate some of the approaches that are available

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to develop an integrated epidemiologic approach, one that will incorporate ecological, social, and behavioral sciences, and help point the way to addressing the challenges posed by emerging infectious diseases. The contributions also show that infectious disease epidemiology not only requires such an approach, the discipline lends itself to this approach and offers good test cases for developing and achieving a new, broader synthesis in epidemiology.

As AIDS and other emerging infections have now demonstrated all too well, no single approach, and no single discipline, is sufficient to identify and prevent emerging and reemerging infections. We have acquired, and must continue to acquire, a great deal of knowledge derived from applied and basic research. To be effective, the knowledge that has been amassed in various areas must be integrated and applied to surveillance and prevention programs. There are great potential benefits, and the epidemiologic paradigms developed are likely to be applicable far beyond infectious diseases.

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