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PUBLIC HEALTH SURVEILLANCE IN THE UNITED STATES

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In 1963, Alexander D. Langmuir defined disease surveillance as "the continued watchfulness over the distribution and trends of incidence through the systematic collection, consolidation and evaluation of morbidity and mortality reports and other relevant data" and the regular dissemination of data to "all who need to know" (1, pp. 182–183). Langmuir was careful to distinguish surveillance both from direct responsibility for control activities and from epidemiologic research, although he recognized the important interplay among epidemiologic studies, surveillance, and control activities. In 1968, the 21st World Health Assembly held technical discussions on the National and Global Surveillance of Communicable Disease and identified these main features of surveillance: 1) the systematic collection of pertinent data; 2) the orderly consolidation and evaluation of these data; and 3) the prompt dissemination of the results to those who need to know, particularly those who are in a position to take action (2).

Subsequently, the applications of surveillance concepts have broadened to include a wider range of health data—risk factors, disability, and health practices—as well as disease. This is reflected in the 1986 Centers for Disease Control (CDC) definition of epidemiologic surveillance:

> Epidemiologic surveillance is the ongoing systematic collection, analysis, and interpretation of health data essential to the planning, implementation, and evaluation of public health practice, closely integrated with the timely dissemination of these data to those who need to know. The final link in the surveillance chain is the application of these data to prevention and control. A surveillance system includes a functional capacity for data collection, analysis, and dissemination linked to public health programs (3, p. ii).

A critical word in this definition is "ongoing"; one-time surveys or sporadic studies do not constitute surveillance. An ongoing system of data collection and collation is also not sufficient to constitute public health surveillance, because to be useful the data must be integrated into the conduct and evaluation of specific public health programs, which may include epidemiologic research leading to prevention.

The purpose of this review is to describe the historical and current practice of public health surveillance, to discuss new directions for surveillance both in terms of new public health priorities and new methodological tools, and to assess the limitations of surveillance.

HISTORICAL OVERVIEW

Current concepts of public health surveillance have evolved from public health activities developed to control and prevent disease in the community. In the late Middle Ages, governments in Western Europe assumed responsibility for both health protection and health care of the population of their towns and cities (4). A rudimentary system of monitoring illness led to regulations against polluting streets and public water, instructions for burial and food handling, and the provision of some types of care. In the 17th century, John Graunt used the Bills of Mortality to monitor dis-

Abbreviations: AIDS, acquired immunodeficiency syndrome; CDC, Centers for Disease Control; NCHS, National Center for Health Statistics; NIOSH, National Institute for Occupational Safety and Health; WHO, World Health Organization.

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ease in London (5). In 1766, Johann Peter Frank advocated a more comprehensive form of public health surveillance with his system of police medicine in Germany, which covered school health, injury prevention, maternal and child health, and public water and sewage (4). In addition, the governmental measures to protect the public health were delineated (4).

William Farr (1807–1883) is recognized as the founder of the modern concepts of surveillance (6). As Superintendent of the Statistical Department of the Registrar General's Office of England and Wales from 1839 to 1879, Farr concentrated his efforts on collecting vital statistics, on assembling and evaluating those data, and on reporting them to both responsible health authorities and to the general public.

In the United States, public health surveillance has focused primarily on infectious diseases. Basic elements of surveillance were found in Rhode Island in 1741 when the colony passed an act requiring tavern keepers to report contagious disease among their patrons. Two years later, the colony passed a law requiring reporting of smallpox, yellow fever, and cholera (7).

National disease monitoring activities did not begin until 1850 when mortality statistics based on the decennial census of that year were first published by the federal government for the entire United States (8). In 1878, Congress authorized the forerunner of the Public Health Service (PHS) to collect morbidity reports for use with quarantine measures against pestilential diseases such as cholera, smallpox, plague, and yellow fever (9). In 1893, an act provided for the collection of information each week from state and municipal authorities throughout the United States. By 1901, all state and municipal laws required notification (i.e., reporting) of selected communicable disease to local authorities such as smallpox, tuberculosis, and cholera (10). In 1914, PHS personnel were appointed as collaborating epidemiologists to serve in state health departments to telegraph reports weekly to the Public Health Service. It was not until 1925, however, following markedly increased reporting associated with the severe poliomyelitis epidemic in 1916 and the influenza pandemic of 1918–1919, that all states were participating in national morbidity reporting (11). After a 1948 PHS study led to the revision of morbidity reporting procedures, the National Office of Vital Statistics assumed the responsibility for morbidity reporting. In 1949, weekly morbidity statistics that had appeared for several years in *Public Health Reports* were published by the National Office of Vital Statistics. In 1952, mortality data were added to what is now known as the *Morbidity and Mortality Weekly Report.* Since 1961, this publication has been the responsibility of CDC.

The Malaria Eradication Program was undertaken by CDC and state health departments in 1946 to address endemic malaria in the United States at a time when World War II veterans were returning from Africa and from the Mediterranean and Pacific theaters and introducing *Plasmodium vivax* to the population (1). Spraying of dichlorodiphenyltrichloroethane (DDT) had begun before surveillance was initiated. By 1947, it was clear that earlier reports of morbidity and mortality had been erroneous. Mississippi, South Carolina, and Texas had the highest reported incidences of malaria, but because there was no diagnostic verification, the reported occurrence was exaggerated. A change in reporting requirements that included case reports with diagnostic verification was illuminating. In Mississippi, for example, the reported incidence of provisional cases dropped from 17,764 to 914 in the first year, only a very few of which could be confirmed. Such new criteria revealed that malaria had disappeared as an endemic disease from the South. The malaria experience was a major factor emphasizing the necessity of a more current and comprehensive system of surveillance.

The critical demonstration in the United States of the importance of surveillance was made following the Francis Field Trial

of poliomyelitis vaccine in 1955 (12, 13). Within two weeks of the announcement of the results of the Field Trial and initiation of a nationwide vaccination program, six cases of paralytic poliomyelitis were reported through the notifiable disease reporting system to state and local health departments; case investigations revealed that these children had received vaccine produced by a single manufacturer. The Surgeon General requested the manufacturer to recall all outstanding lots of vaccine and directed that a national poliomyelitis surveillance program be established at CDC. Intensive surveillance and appropriate epidemiologic investigations by federal, state, and local health departments found 141 vaccine-associated cases of paralytic disease, 80 of which were found in family contacts. Daily surveillance reports were distributed by CDC to all persons involved in these investigations. This national common-source epidemic was ultimately related to a particular brand of vaccine that had been contaminated with live virus. Had the surveillance program not been in existence, many and perhaps all vaccine manufacturers would have ceased production.

Surveillance was critical to the containment strategy for global eradication of smallpox, and the success of the program demonstrated to the international community the practical value of surveillance (14). To facilitate early outbreak detection, surveillance teams actively investigated reported cases, sought nearby cases, and initiated rapid containment measures. Surveillance was intensified in areas in which cases were confirmed. When outbreaks decreased, these teams continued to search high-risk areas for cases until independent assessment confirmed that transmission had been interrupted. Routine reporting of cases and the work of the surveillance teams were further supplemented in some settings by one-week, village-level, intensive case identification. These surveillance activities were clearly linked to containment measures that included isolating patients at home and rapidly vaccinating persons in surrounding houses. Key population contacts for surveillance included not only government officials and religious leaders but also school children, tea shop owners, people in markets, nomads, and refugees.

The Conference (now Council) of State and Territorial Epidemiologists was authorized in 1951 by its parent body, The Association of State and Territorial Health Officials, to determine what diseases should be reported by states to the Public Health Service and to develop reporting procedures. The Council currently meets annually and, in collaboration with CDC, recommends to its constituent members appropriate changes in morbidity reporting and surveillance, including what diseases should be reported to CDC and published in the *Morbidity and Mortality Weekly Report.*

Until 1950, the term surveillance was restricted in public health practice to watching contacts of serious communicable diseases, such as smallpox, to detect early symptoms so that prompt isolation could be instituted (15). Langmuir has been credited with broadening the application of surveillance to populations (1), and in 1968, the 21st World Health Assembly focused on national and global surveillance of communicable diseases, applying the term to diseases rather than to the monitoring of individuals with selected communicable diseases (2). Over the intervening years, a wide variety of health events, such as childhood lead poisoning, leukemia, congenital malformations, abortions, injuries, and behavioral risk factors have been brought under surveillance. In 1976, recognition of the breadth of surveillance activities throughout the world was made evident by a special issue of the *International Journal of Epidemiology* devoted to papers specially commissioned to examine health surveillance (16).

In 1986, CDC, in collaboration with the Council of State and Territorial Epide-

miologists, published its first Comprehensive Plan for Epidemiologic Surveillance (3). In this document, CDC explicitly delineated its policies and goals in surveillance, specified plans to establish and evaluate surveillance systems, and described relevant activities in research and training.

Since the term surveillance was first applied to a disease rather than to an individual in 1950, it has assumed major significance in disease control and prevention. Its specific connotations, however, have not been universally understood. In 1963, Langmuir clearly limited surveillance to the collection, analysis, and dissemination of data (1). The term did not encompass direct responsibility for control activities. In 1965, the Director General of the World Health Organization (WHO) established an Epidemiological Surveillance Unit in the Division of Communicable Diseases at WHO (17). The Division Director, Karel Raska, defined surveillance much more broadly than Langmuir and included in it "the epidemiological study of disease as a dynamic process." In the case of malaria, he saw epidemiologic surveillance as encompassing control and prevention activities. Indeed, the WHO definition of malaria surveillance included not only case detection but also taking of blood films, drug treatment, epidemiologic investigation, and follow-up (18).

The 1968 World Health Assembly discussions reflected the broadened concept of epidemiologic surveillance and addressed the application of the concept to public health problems other than communicable diseases (2). In addition, epidemiologic surveillance was said to imply "the responsibility of following up to see that effective action has been taken" (2, p. 9).

The use of epidemiologic to describe surveillance first appeared in the mid-1960s and was associated with the establishment of the WHO unit of that name. This was done both to distinguish this activity from other forms of surveillance, such as for military intelligence, and to reflect its broadened applications. The use of the term epidemiologic, however, also engendered both confusion and controversy. In 1971, Langmuir noted that some epidemiologists tend to equate surveillance with epidemiology in its broadest sense, including epidemiologic investigations and research (15, p. 12). He found this "both etymologically unsound and administratively unwise," favoring a definition of surveillance as "epidemiological intelligence."

Surveillance activities, however, have frequently led to epidemiologic investigations of etiology. After the initiation of the National Influenza Immunization Program in October 1976, cases of Guillain-Barré syndrome were reported to CDC through a nationwide surveillance system established to monitor illnesses occurring after influenza vaccination (19). Subsequent epidemiologic studies demonstrated a relation of Guillain-Barré syndrome to the swine influenza vaccine that was in use, which resulted in the cessation of the vaccination program for the year (20). To test whether the syndrome could result from use of other influenza vaccines, a special surveillance system was established in 1978 which used 1,813 neurologists as reporters (21). The data collected for that and several subsequent years showed no association between influenza vaccines and Guillain-Barré syndrome.

In addition, public health surveillance systems are often the source of cases for case-control studies. For example, in response to concerns expressed by Vietnam veterans about the possibility of increased risk for fathering children born with birth defects, CDC conducted a case-control study using as cases with serious structural birth defects infants identified by the Metropolitan Atlanta Congenital Defects Program (22). This surveillance system attempted to ascertain all infants with defects diagnosed during the first year of life born to mothers who resided in the Atlanta area. Cases and controls were selected from infants born alive in the Atlanta area dur-

ing the years 1968 through 1980. This study found that Vietnam veterans did not have an increased risk of fathering children with defects. Other examples of epidemiologic research facilitated by case ascertainment through surveillance include the demonstration of the association of tampon use with the development of toxic shock syndrome (23), the relation between salicylate use and Reye's syndrome (24), the risk of breast cancer associated with long-term oral contraceptive use (25), and quantification of the risk of acquired immunodeficiency syndrome (AIDS) from certain sexual practices (26).

We believe that there are two issues to be addressed in this discussion. First, what are the boundaries of surveillance practice? Second, is epidemiologic an appropriate modifier of surveillance as it is used in public health practice? To address these questions, we must first examine the structure of public health practice. One can divide public health activities into surveillance, epidemiologic and laboratory research, service (including program evaluation), and training. Surveillance data should be used to identify areas needing research and service which, in turn, help to define training needs. Unless data are provided to those who set policy and implement programs, their use is limited to archives and academic pursuits and are appropriately considered to be health information rather than surveillance data. Surveillance, however, does not encompass research or service. These are related but independent public health activities and may be based on surveillance. Hence, the boundary of surveillance practice is drawn before the actual conduct of research and the implementation of delivery programs.

Given this context, the use of the term epidemiologic to modify surveillance is misleading. Epidemiology is a broad discipline that incorporates research and training that is distinct from a public health process that we call surveillance (table 1). Because of the much broader content of epidemiology, the use of epidemiologic confuses the meaning of surveillance in the public health setting, having led in the past to the inappropriate incorporation of research into the definition of surveillance (18). For this reason, in this paper, we will not adhere to the current practice of using the term epidemiologic to modify surveillance. We propose that a more appropriate term is *public health* surveillance, because its use retains the original benefits of the term epidemiologic cited previously and removes some of the confusion surrounding current practice. Surveillance is more correctly an element of public health, and persons encountering the term should understand this.

SURVEILLANCE PRACTICE

Data collection

Surveillance data are collected from multiple sources. Physicians, laboratories, and other health care providers are required to report all cases of those diseases or health conditions specified by state law to be notifiable (or reportable); most of these conditions are of infectious origin. Typically, a case report form is completed for each case by the health care provider or laboratory and mailed to the local or state health department. In some states, the authority to change the list of notifiable diseases is granted to the state health authorities; in other states, each change must be newly legislated. Penalties for failure to report a notifiable condition may include suspension of a physician's license (27), but in practice such penalties are rarely enforced. Physician reporting is influenced by disease severity, availability of public health measures, public concern, ease of reporting, and physician appreciation of public health practice in the community.

A disease traditionally is notifiable only when there is a clear link between a case report and a public health action. For many of these diseases, case investigations are performed by the state or local health department. Individual names and other personal identifiers are often required for purposes of contact identification or treat-

TABLE 1

Distinctions between public health surveillance and epidemiologic research

	Public health surveillance	Epidemiologic research
Reason for initiating data collection	Problem detection Problem description Identify cases for epidemiologic studies *May be legally required* Monitor geographic and temporal trends in disease occurrence	Hypothesis testing Problem description
Frequency of data collection	Ongoing	Usually time-limited
Method of data collection	Established systems or procedures Many persons involved Traditionally depends on voluntary participation	Special procedures tailored to hypotheses or questions of interest Fewer persons involved Depends on paid, supervised employees
Amount of data collected per case	Usually minimal	Can be considerable and usually detailed
Completeness of data collected	Often incomplete	Usually complete
Analysis of data	Traditionally simple Primarily to detect change in incidence Usually historical comparison groups	Can be complex Hypothesis testing often requires statistical methods Concurrent controls
Dissemination of data	Timely Regular Review in public health agency Targeted to public health and clinical audience	Not timely Sporadic External review Targeted to academic as well as public health and clinical audience
Use of data	Identifies a problem Triggers intervention Suggests hypotheses Commonly used to evaluate programs *Estimates magnitude of a problem*	Describes a problem in detail Provides etiologic information Tests hypotheses, suggests additional hypotheses Less often used to evaluate programs

ment. In addition, collecting names aids in identifying duplicate reports. Because of the need to identify individuals, however, concerns about confidentiality affect notifiable disease reporting, and individual identifiers are not usually collected at the national level. These concerns have been heightened by the epidemic of AIDS (28).

The Council of State and Territorial Epidemiologists determines which notifiable diseases should be reported from the state health department to CDC. In addition, the quarantinable diseases—yellow fever, cholera, and plague—are reportable by international regulation. To obtain information (case reports) on specific topics such as birth defects, influenza, low birth weight, and nosocomial infections, CDC has collaborated with state and local health departments to establish specialized disease reporting systems. Other federal agencies are involved in the collection of surveillance data; for example, the Food and Drug Administration (FDA) conducts postmarketing surveillance of adverse reactions to drugs (29), and the Consumer Product Safety Commission conducts surveillance of product-related injuries (30).

For many health events, national surveillance systems rely on data collection efforts by the National Center for Health Statistics (NCHS) of CDC, including the National Health Interview Survey (31), the National Hospital Discharge Survey (32), and the National Health and Nutrition Examination Survey (33) (table 2). Although such surveys do not constitute public health surveillance systems, data obtained in these

TABLE 2

Selected national data sources that support public health surveillance, United States

Title	Scope	Responsible organization	Sources of data	Dates
Ambulatory Sentinel Practice Network for North America	National (unrepresentative)	Ambulatory Sentinel Practice Network	Family physicians	1981–present
Boating Accident Reporting System	National	Coast Guard	Boat operators	1961–present
Fatal Accident Reporting System	National	Department of Transportation	Police records, vital records, medical examiners, coroners, hospital records	1975–present
Hazardous Materials Information System	National	Department of Transportation	Highway patrol	1971–present
McAuto	National (unrepresentative)	McDonnell-Douglas Corporation	Hospital discharge abstracts	1982–present
National Accident Sampling System	National (unrepresentative)	Department of Transportation	Police, hospitals	
National Ambulatory Medical Care Survey	National	NCHS (CDC)*	Office-based, medical practices	1973–1981, 1986
National Burn Registry	National (unrepresentative)	National Institute of Burn Medicine	Burn centers	1964–present
National Disease and Therapeutic Index	National	IMS, Inc.	Office-based, medical practices	1960–present

National Fire Incident Reporting System	National	Federal Emergency Management Administration	Fire marshalls	1976–present
National Health Assessment and Nutrition Examination Survey	National	NCHS (CDC)	Population survey respondents	1971, 1976, 1982, 1988
National Health Interview Survey	National	NCHS (CDC)	Household interview respondents	1957–present
National Hospital Discharge Survey	National	NCHS (CDC)	*Hospital discharge*	1965–present
National crime survey	National	Justice Department	Victims	1972–present
Professional Activities Study	National (unrepresentative)	Commission of Professional and Hospital Activities	Hospital discharge abstracts	1953–present
Uniform crime reports	National	Federal Bureau of Investigation	Police	1930–present
Vital statistics	National	NCHS (CDC)	Death certificates, birth certificates	1925–present

* In June 1987, The National Center for Health Statistics (NCHS) became a component of the Centers for Disease Control (CDC).

surveys can be used as part of surveillance systems that are more clearly linked to public health practice (table 3). Similarly, hospital abstracting services, such as the Commission of Professional and Hospital Activities (34), provide information on more than 50 per cent of all acute-care civilian hospital discharges in the United States. In addition, more than half of the states have enacted legislation placing hospital discharge or claims data into the public domain (35). Again, such data collection activities do not constitute surveillance systems, but may provide useful data for surveillance.

There are relatively few national data sets in the area of ambulatory care, and these are used only rarely for surveillance purposes (36–38). National data on diagnosis and drug therapy from office-based practices are available from the National Ambulatory Medical Care Survey of NCHS (36) and the commercially available National Disease and Therapeutic Index (37). National influenza surveillance efforts have been complemented by a convenience sample of family practitioners that provides CDC with demographic data and culture specimens for all cases of influenza-like illness seen in their offices during influenza season (38). Emergency room data are found in the National Electronic Injury Surveillance System maintained by the Consumer Product Safety Commission (39) and the Drug Abuse Warning Network supported by the National Institute on Drug Abuse (40).

Registries are also useful sources of information (41). Unlike national surveys conducted by NCHS, registries are designed to collect information on a specific topic and are usually limited in scope. Like the NCHS surveys, registries are not surveillance systems, but data from registries can be used for public health surveillance. CDC's Metropolitan Atlanta Congenital Defects Program is an example of a registry that has been developed into a system of public health surveillance (42). The best

TABLE 3

Selected national public health surveillance systems, United States

Title	Scope	Responsible organization	Types of data	Dates
Adverse drug reaction program	National	Food and Drug Administration	Pharmaceutical manufacturers, physicians	1969–present
Behavioral Risk Factor Survey	National (unrepresentative)	CDC* via state health departments	Household telephone survey	1981–present
Birth Defects Monitoring Program	National (unrepresentative)	Commission of Professional and Hospital Activities	Hospital discharge abstracts	1970–present
Disease- and condition-specific surveillance systems†	National	CDC via state health departments	Physicians, hospitals, laboratories	Various, by condition (since 1954)
Fatal Accident Circumstances and Epidemiology	National	National Institute for Occupational Safety and Health (CDC)	Medical examiners	1980–present
National Electronic Injury Surveillance System	National	Consumer Product Safety Commission	Emergency rooms	1972–present
National Notifiable Disease Surveillance System	National	CDC via state health departments	Physicians hospitals, laboratories	1920–present
Nutrition (pediatrics and pregnancy)	National (unrepresentative)	CDC	Public clinics	1975–present
Surveillance, Epidemiology, and End Results	National (unrepresentative)	National Cancer Institute	Cancer registry	1972–present

* CDC, Centers for Disease Control.

† This includes approximately 80 independent surveillance systems for specific diseases or conditions, mostly infectious.

known and most widely used registries are those for cancer. There are population-based cancer registries in 38 states; 11 of these are part of the National Cancer Institute's Surveillance, Epidemiology, and End Results Program (43).

Data collation and analysis

Data on infectious diseases are collated and analyzed in local and state health departments as well as at CDC. Descriptive statistics, including sex, age, race, and county of occurrence, have been the most useful for analyzing infectious disease data with emphasis on total number of cases for a defined time period (e.g., weekly for notifiable diseases). Additional analyses for trends over time and summary statistics on demographic information on cases may be performed, and rates of disease may be calculated. An exception to these limited analyses has been the application of regression and time series analyses to mortality data for the surveillance of influenza (44–46).

Public health surveillance of noninfectious conditions emphasizes population-based rates of disease. Linkage of data sources has facilitated calculation of rates and improved reporting (e.g., birth-weight-specific death rates linked by birth and death certificates) (47). Typically, health department statistical staff calculate disease rates by sex, race, and age. In addition, trends over time (by year for most chronic conditions) are determined. In the past, only national and regional data have been available for estimates of morbidity related to many noninfectious conditions, and few small-area comparisons have been made. As increasingly large morbidity data sets are being used (e.g., hospital discharge abstracts), the number and variety of applications are increasing (35).

Dissemination of data

An important purpose of data analysis and dissemination is to provide easily understood information in tabular or graphic formats (in contrast to raw data) to those who implement or influence public health practice. Public health surveillance data can be used to inform policymakers and the public about the nature and extent of health problems and to persuade these audiences to address particular issues. In this way, a health agency can develop a constituency to support public health programs and to justify the expenditure of public funds.

More than half of all state health departments and 40 per cent of county health departments publish surveillance data in a routine bulletin or newsletter for the local medical and public health community (48). State-specific notifiable disease data are presented weekly in tabular format in CDC's *Morbidity and Mortality Weekly Report*. Infectious disease data are also published annually in the *CDC's Summary of Notifiable Diseases* and in similar publications by state health departments. In 1982, CDC began publishing the *CDC Surveillance Summaries*, which contains surveillance reports on specific health events for which CDC has program responsibilities. Surveillance data from other agencies may be published in special publications (e.g., the FDA Drug Bulletin). State and local health department reports, federal publications like the *Morbidity and Mortality Weekly Report*, and peer-reviewed public health and clinical journals, however, are the most common forms of disseminating surveillance data. The "Rainbow Series" of NCHS publications reflects data collected and analyzed from vital statistics and national surveys (49). Although NCHS data sets are not specifically linked to public health programs, they are frequently used to establish policy and monitor the effect of national intervention programs (50).

Application to program

The concept of public health surveillance has evolved from primarily an archival function prior to 1950 to one in which there is timely analysis of the data with an appropriate response. Because surveillance is part of public health practice, it should be

used to guide control and/or prevention measures (or relevant research). No public health surveillance system is complete without being linked to action. The uses of surveillance include detecting new health problems (e.g., antibiotic-resistant strains of bacteria), detecting epidemics, documenting the spread of disease, providing quantitative estimates of the magnitude of morbidity and mortality, describing the clinical course of disease, identifying potential factors involved in disease occurrence, facilitating epidemiologic and laboratory research, and assessing control and prevention activities (51).

Surveillance has been vital to developing hypotheses and stimulating epidemiologic research. Historically, acute infectious disease problems have almost always been defined by epidemiologists in terms of their temporal and geographic patterns. The need to define chronic as well as acute diseases in terms of temporal and geographic trends is being increasingly recognized (52).

Public health surveillance efforts have often been intensified when the means for primary prevention of most or all cases is at hand (e.g., vaccine for measles or smallpox) or when the disease is severe and newly emerging, with major efforts being made to develop control and prevention measures (e.g., toxic shock syndrome). Additionally, public health surveillance has served as the means for identifying persons with a health problem who can participate in epidemiologic studies for developing prevention strategies (53). Even before AIDS was documented to have a viral etiology, for example, measures to lower a person's risk of disease were suggested by studies of cases detected through public health surveillance (26).

Evaluation of surveillance programs

Established surveillance systems require regular review and modification based on explicit criteria of usefulness, cost, and quality (51). Most published evaluations of surveillance systems have been limited to infectious diseases (54–57), although there have been some efforts to assess the appropriateness of various data sources for the surveillance of other kinds of health problems (58–60).

A surveillance system is useful if it can be applied to a public health program to control and prevent adverse health events or to better understand the process leading to an adverse outcome. The simplest way to assess usefulness is to ask those involved in public health practice by means of interviews or surveys (48, 61, 62). A more rigorous approach to defining usefulness is through the assessment of the impact of surveillance data on policies and interventions (63), but there are no published studies of this kind. Decisions affecting public health surveillance programs are more often based on changes in more general program directions than on detailed analysis of a particular system (e.g., directing resources away from routine contact tracing for gonorrhea control to programs for preventing AIDS).

The economic analysis of surveillance systems has received little systematic attention apart from the accounting of direct costs to health agencies. In a 1983 report from Vermont, the authors reasoned that costs were too high to justify active, health-department-initiated surveillance of selected acute infectious diseases unless unquantified subjective benefits, such as improved relations with practicing physicians, were great (56). In a 1985 report from Kentucky, on the other hand, the benefits associated with health-department-initiated surveillance of hepatitis A were found to outweigh the costs (64).

CDC has proposed a systematic method to evaluate surveillance systems on the basis of usefulness and cost as well as seven attributes of quality: sensitivity, specificity and predictive value positive, representativeness, timeliness, simplicity, flexibility, and acceptability (51, 65). These attributes of a surveillance system are interdependent, and the improvement of one may improve or compromise another. Increasing

the sensitivity of a system to detect a greater proportion of a given health event in a population may also improve representativeness and usefulness of the system, yet may lead to greater cost, lower specificity, and more false positive events. This method of evaluation is currently being used to assess all surveillance systems at CDC at least once every three years. Such an approach for evaluating surveillance systems should enable public health practitioners to efficiently assess their surveillance practices and thus improve the delivery of public health services.

NEW PUBLIC HEALTH PRIORITIES

Chronic diseases

Better data are essential for progress in chronic disease prevention and control, particularly incidence data to establish priorities and to evaluate programs (66). These data should describe the burden and the determinants of disease and help to evaluate programs.

Three aspects of chronic diseases make surveillance difficult. First, for some diseases (e.g., mesothelioma following asbestos exposure), the latency between a precipitating event or exposure and the eventual chronic disease not only hinders linkage between exposure and outcome but also complicates development and evaluation of prevention programs. Second, the multifactorial etiology of many chronic conditions often prevents accurate linkage between exposures, risk factors, or interventions and outcomes. Third, because the public health community is often interested in arresting or reversing the progression of a chronic condition, surveillance of various stages of disease is important.

There has been extensive experience in data collection and analysis of chronic disease occurrence. Indeed, at the community level, there have been many examples of monitoring of heart disease, stroke, and cancer, although these programs are typically not ongoing, are usually limited to data collection and analysis, and are rarely directly linked to public health prevention programs. For example, since 1945, population-based community studies on the natural history of stroke have been conducted on data collected from medical records and death certificates in Rochester, Minnesota (67). Similar community studies have been conducted on cardiovascular disease (68, 69). For cancer, the most successful approach to community-based surveillance has been the use of registries (43, 70), an approach that has also been used for stroke (71) and hypertension (72).

For various chronic conditions, efforts have been made to obtain comprehensive data not only from medical records and death certificates but also from special surveys (73, 74). Cancer has become a notifiable disease in at least 36 states in an effort to broaden the scope of data collection for that condition (T. Aldrich, Oakridge National Laboratories, personal communication, 1988).

At the state and national levels, large data sets are available for application to the surveillance of chronic diseases (table 1). For example, national stroke mortality (75) and cancer deaths (76) have been monitored using death certificate data available from the NCHS. An alternative approach to the use of such national data bases is the pooling of information from state and local sources to monitor national trends, as has been done with nutrition data. Data on height and weight obtained from publicly supported health and nutrition programs demonstrated high prevalences of growth stunting in Native American and Hispanic children (77). This finding, together with high weight-for-height in these populations, suggests that the diet of these children is adequate in quantity but inadequate in quality of nutrient intake. If confirmed, such findings call for nutritional programs focused on high quality protein and increased essential vitamins rather than simply increased calories. Although pooling of state data is less efficient than conducting national samples, the close linkage at the state level of data collection and analysis

to program intervention is an important consideration. In addition, there have been efforts to bring together national data from various sources for chronic health problems, such as esophageal cancer (78) and alcohol abuse and alcoholism (79).

The Surveillance, Epidemiology, and End Results Program of the National Cancer Institute is an elaborate registry of incident cancers in 11 geographic areas in the United States which provides detailed population-based information on mortality due to malignant neoplasms (43). It is the principal source of national estimates of site-specific cancer incidence and trends, documenting increases in cancer of the lung and bronchus and declines in the incidence of gastric cancer (80). This program, which costs about $5,800,000 annually, is particularly useful for national trend estimates and epidemiologic research. Its uses for local prevention and control activities, however, have been limited. Less elaborate state cancer registries may be more closely linked to state cancer control efforts (70).

None of these data collection activities constitute public health surveillance systems. The usefulness of existing data sets for chronic disease surveillance has not been proven. Such data may, nonetheless, prove useful for public health and are essential to assess the completeness and accuracy of existing chronic disease data and their appropriateness for this purpose. To date, there has been a limited effort to apply the principles of public health surveillance to specific chronic conditions (81) or to assess alternative approaches to collecting chronic disease data for public health surveillance (82–84).

Occupational safety and health

In 1984, J. Donald Millar, the Director of the National Institute for Occupational Safety and Health (NIOSH), told Congress that federal surveillance of occupational illness was "70 years behind that of communicable disease surveillance" (85, p. 11). Before the enactment of the 1970 Occupational Safety and Health Act, no comprehensive national data base on workplace hazards existed (86).

Major efforts are currently under way to perform surveillance of occupational diseases both at the national and state levels. Although past efforts have focused on data gathering and analysis, current efforts are motivated by attempts to collect data in a way that will lead directly to intervention. NIOSH first developed a list of the "Ten Leading Work-related Diseases and Injuries" and is now identifying those occupations and industries at high risk for adverse health events (87).

A survey of states conducted by the Iowa Department of Health in 1985–1986 showed that at least 30 (60 per cent) states had either voluntary or mandatory reporting programs for selected occupational health conditions (88). The states have not been uniform, however, concerning the conditions for which they require reporting, although lead poisoning, silicosis, and asbestosis are frequently included on the reportable disease list. Also, the reporting criteria for these occupational health events are not uniform across states (e.g., Texas requires reporting of blood lead levels >40 mg/ml, whereas New York requires reporting of all blood lead levels >25 mg/ml) (P. Honchar, CDC, personal communication, 1987).

Although many state health departments have reporting laws, few have maintained a professional staff that could respond to the incoming reports. Fortunately, this gap in surveillance is being addressed. For example, the Texas Department of Health performs case investigations routinely in response to reported cases of occupationally acquired lead poisoning (P. Honchar, CDC, personal communication, 1987). Case investigation includes 1) assuring proper clinical management of the affected person and 2) offering an evaluation of the worksite to detect factors potentially responsible for the case. This evaluation is accompanied by recommendations for preventing further cases. Screening for elevated blood lead levels in coworkers may be conducted.

As another example, NIOSH is conducting the Fatal Accident Circumstances and Epidemiology Project, which focuses upon selected electrical-related and confined space-related fatalities (89). The purpose of the program is to identify factors influencing the risk of fatal injuries in the workplace.

In addition to data gained from case reports, 30 states now include occupational information on death certificates; only 18 states collected such information in 1981 (90). Fourteen health departments include parents' occupations on the birth certificate. Reporting to health departments will be expanded through the Sentinel Event Notification System for Occupational Risks, a NIOSH-sponsored health event reporting system based on reporting selected occupational disease and injury outcomes amenable to control and prevention (E. Baker, CDC, personal communication, 1987). Other data used by state health departments for surveillance include hospital discharge data, workmen's compensation data, and cancer registries (11 states report occupational history on all cancer cases). At the national level, questions on health outcomes and health risks of relevance to occupational health have been incorporated into the National Health and Nutrition Examination Survey and the National Health Interview Survey.

Health effects of environmental toxic exposures

Public health surveillance in environmental health includes both hazard (exposure) and health effects monitoring. An example of an ongoing national system for collecting data on potential exposures is the Hazardous Materials Information System of the Department of Transportation, which was established in 1971 by a federal law that seeks voluntary reporting of spills occurring during interstate commerce (91). Comparisons of these reports with independently collected data from the state of Washington, however, indicated that the federal system missed over 80 per cent of spills and had inadequate data on injury, death, and cost (91). The state of California compared data from the Hazardous Materials Information System with similar information collected by the California Highway Patrol related to hazardous material spills to determine number and nature of incidents (59). Of 941 incidents involving highway transport of hazardous materials and related exposures and injuries, only 18 were reported in both systems. Despite such limitations, the Hazardous Materials Information System could be integrated into a system of public health surveillance because it offers useful data on place, cause, and mode of spill.

The most extensive public health surveillance system developed for outcomes related to an environmental hazard evolved from 62 childhood lead-poisoning prevention programs (92). Over a 10-year period ending in 1981, 247,000 children with lead toxicity were identified among nearly 4 million screened. The data were disseminated at both the local and national levels and were applied to program planning and implementation. This routine reporting system was complemented with data from the Second National Health Assessment and Nutrition Examination Survey (92). These data sources documented the decrease in blood lead levels associated with the reduction of lead used in gasoline. When federal funding was discontinued in 1981, the national program stopped, and most local activities were curtailed or eliminated.

More typically, public health surveillance of specific environmental health outcomes is established, often in the form of registries, and then attempts are made to relate these outcomes to particular exposures or etiologies. Important examples are the systems established for the surveillance of congenital malformations. Widespread interest in birth defects followed the epidemic of limb reduction deformities which was associated with women taking thalidomide during early pregnancy. This event, coupled with epidemiologic patterns for several malformations indicative of an environ-

mental etiology, led to the establishment of the Metropolitan Atlanta Congenital Defects Program and the nationwide Birth Defects Monitoring Program in 1967 and 1974, respectively (42). These two systems are used to monitor trends in specific birth defects or combinations of defects and to stimulate epidemiologic investigations when increases are identified. The data have been used to demonstrate the lack of teratogenicity of exposures of serious public concern such as spray adhesives (93), vinyl chloride (34), airport noise (94), and military service in Vietnam (22). Similarly, cancer registries have been used to study possible relations between specific cancers and environmental exposures (43).

The first challenge in the public health surveillance of environmental hazards is to determine which hazards warrant ongoing programs of surveillance. The major constraint of the outcome approach is the limited knowledge of the health effects of specific toxins (i.e., natural) and toxicants (i.e., man-made), which inhibits our ability to detect unexpected associations between disease and exposure. Humans have released thousands of toxins and toxicants into the environment, but both the health impact and the exposure potential of most of these substances are unknown or, at best, established only in laboratory animals. The Agency for Toxic Substances and Disease Registry has been given the responsibility of ranking the leading priority chemicals in terms of risk to human health (95). Yet, even when this task has been accomplished, policies for establishing systems of public health surveillance will need to be formulated by local, state, and federal agencies.

Once priorities are established, data must be identified for both exposures and outcomes. Fortunately, many data sets (e.g., the Birth Defects Monitoring Program) already exist for both and need only to be integrated into public health programs (42). It is simpler and less costly to use existing data and data systems than to establish new ones. Additionally, historical data enable one to analyze long-term trends.

Public health surveillance in a disaster setting is critical to the optimal allocation of scarce and often poorly organized resources. Surveillance systems were established, for example, to monitor exposure to radiation following the incident at the nuclear reactor at Three Mile Island (96). Surveillance systems were also developed to monitor the health effects of the volcanic ash plume created by the eruption of the Mount St. Helens volcano in 1980 (97) and the health effects of exposure to toxic waste at Love Canal (98). Similar short-term, local environmental monitoring systems have been established in response to chemical spills (99). Although these are examples of ad hoc surveillance established in an acute situation, there are few examples of ongoing systems of public health surveillance linked to public health programs of control and prevention. Occasionally, emergency preparedness plans include surveillance, such as during the 1984 Olympics when the potential for terrorist activities was considered high (100). Currently, CDC is working with the American Red Cross to organize disaster surveillance and to establish an international activity in this area (P. Duclos, CDC, personal communication, 1987).

Finally, there have been efforts to combine environmental monitoring data with health outcome information. After the severe heat wave of 1980, for example, CDC, in collaboration with medical examiners, state and local health departments, and the National Weather Service, developed a system of surveillance of mortality related to summer heat waves (101).

Injuries

The recognition of both intentional (e.g., homicide) and unintentional (e.g., falls) injuries as major public health problems has led to the need for developing systems of public health surveillance (102–104). Because of the acute nature of injury events, surveillance principles learned from experience with acute infectious diseases are often readily adaptable to injuries (105). The current approach to establishing public

health data bases for injury has been to adapt data, such as medical examiner reports and vital statistics, to public health needs (103, 105). This approach has been used most widely at the state level where vital statistics, hospital discharge data, emergency room data, and household surveys have been used to measure the extent and nature of the unintentional injury problem in particular populations, as well as to assess the impact of prevention programs (102, 106–108). Medical examiner data have also been used in the surveillance of injuries and associated risk factors such as alcohol and drug use (109).

Approaches to injury surveillance vary at the state and local levels. During one year, the Statewide Childhood Injury Prevention Program in Massachusetts detected 5,953 fatal and nonfatal injuries in 87,022 children and adolescents through a public health surveillance system based on hospital and emergency room records from 23 hospitals in 14 communities (102). Using these data, program personnel focused prevention resources on the injury problems of highest incidence in particular communities. In 1987, the Council of State and Territorial Epidemiologists adopted a resolution to recommend that spinal cord injury be made reportable in all states (168). North Dakota has already made notifiable all injuries resulting in at least one day of disability (J. Pearson, North Dakota State Department of Health, presented at the annual Council of State and Territorial Epidemiologists meeting, May 1987). Trauma registries can also be adapted for surveillance (110).

Several national data sets are available for the surveillance of unintentional injuries (table 2). NCHS compiles and analyzes mortality statistics, hospital discharge data, office-based physician utilization data, and data collected in an ongoing health interview survey of the general population. Other sources for national data include the National Electronic Injury Surveillance System maintained by the Consumer Product Safety Commission (39), the Fatal Accident Reporting System (111) and the National Accident Sampling System (112) maintained by the National Highway Traffic Safety Administration, the National Burn Registry initiated by the National Institute of Burn Medicine (113), the National Fire Incident Reporting System established by the Federal Emergency Management Agency (114), the US Coast Guard investigations of boating incidents (115), and the National Spinal Cord Injury Network (116). As with chronic diseases, the usefulness of many of these data sources for public health surveillance remains to be assessed.

The challenge of surveillance of intentional injuries is even more complex. Data are available from vital records and medical examiners, but information on the circumstances of homicide and suicide is often absent or limited in these data sets. Public health surveillance of intentional injuries will require the collaboration of the public health community with a new array of experts, especially in the fields of law enforcement and sociology (113). At the state and local levels, data from criminal justice agencies, medical examiners and coroners, and medical and social service agencies are being explored for use in the surveillance of intentional injury (117). Illinois instituted mandatory uniform crime reporting in 1972; the state maintains the data on computer and publishes a report each year (118). Few data exist on morbidity related to assault or child abuse, and only rarely have epidemiologic studies been conducted in this area (119). Efforts are under way to assess the feasibility of alternative approaches to the surveillance of domestic violence (120).

On the basis of data from the national mortality files of NCHS and population estimates of the US Bureau of the Census, a 40 per cent increase in youth suicide was documented in the decade ending in 1980 (121). This increase was found primarily in white males 15–24 years of age. These surveillance data documented the dramatic change of suicide as a problem of the elderly

to a problem of the young. Current efforts in suicide surveillance have demonstrated the importance and difficulty of arriving at uniform definitions, a problem complicated by the interdisciplinary nature of this endeavor. Uniform definitions of child and spouse abuse, problems for which incidence data are sparse, are also needed. Yet, as such data bases are developed, surveillance will play a crucial role in public health programs aimed at controlling and preventing these and other injuries. Other national data sources, such as the Uniform Crime Reports of the Federal Bureau of Investigation and the annual National Crime Survey of the US Department of Justice, have proven to be useful (121–125).

Personal health practices

At a national level, the Health Interview Survey conducted by NCHS has provided the most information on personal health practices such as alcohol use and smoking. The prevention supplements to the 1982 and 1985 surveys have provided more detailed information in this area (126). As the role of personal health behavior in the development of chronic diseases and injuries has become more fully recognized, state-based programs to reduce the prevalences of unhealthy behaviors have been established. In turn, interest in providing a systematic means of collecting population-based prevalence data on a state-specific basis resulted in the initiation of the Behavioral Risk Factor Surveys in 1981 (127).

National estimates can be obtained more efficiently, but local programs benefit from involvement in data collection as well as from the ability to adapt the collection process to their particular needs. As of 1987, 35 state health departments are conducting ongoing surveys of behavioral risk factors in persons aged 18 years or older. Each state uses a standardized questionnaire to determine the prevalence of a variety of personal health practices including cigarette smoking, smokeless tobacco use, alcohol consumption, exercise, seat belt use, dieting, and hypertension control (127). The sample for each survey, conducted by telephone, is selected generally with a multistage cluster design based on the Waksberg method (128).

Interview surveys can obtain personal, health-related information with only minor differences in the prevalence of various health conditions when conducted by telephone or in person (127). Telephone interviews have the advantages of lower cost (about one-third to one-half the cost of personal interviews) and the ease of supervising interviewers. Although there are problems of bias related to omitting those households without telephones, telephone coverage exceeds 93 per cent in the United States (127).

Results of the surveys are published by both CDC and state health departments (129, 130). They are also distributed to the press and to a variety of local and state organizations, including voluntary health agencies, hospitals, health maintenance organizations, and state legislators. In 1986, the 43 states that had conducted these surveys reported that these data were frequently used by the health department to prepare state planning documents and to establish state-level health objectives (62). Sixty-five per cent of these states reported using the data to support legislative initiatives, especially seat belt and anti-smoking legislation (62). Limitations, however, exist when these data are used; many states cited a circumscribed authority to disseminate the findings. In addition, because the surveys only recently have been initiated at the state level, not enough time has elapsed to adequately analyze trends.

Preventive health technologies

Health technology includes the drugs, devices, and medical and surgical procedures used in health care, and the organizational and supportive systems within which such care is provided (131). The implementation of new technologies is a prominent growth industry in health. Dramatic examples, such as carotid endarterectomy, artificial hearts, osteoporosis screening, and AIDS

testing, are very much in the public eye. Concerns regarding premature diffusion or misapplication of health technologies have highlighted the need for routine surveillance of the application of the technologies, particularly as these new technologies are used in healthy or asymptomatic populations to prevent disease (132). Currently, efforts are under way in several state health departments to assess the effectiveness of both cervical cancer and breast cancer screening programs. Systems of public health surveillance are an integral part of these assessments.

There are, however, few examples of surveillance of health technologies despite this widespread diffusion of new devices and practices. Immunization against selected infectious diseases is probably the most effective and well-known technology used in public health. More recently, public health surveillance of selected medical technologies has been developed by CDC in response to concerns in the public health community. For example, in response to state health officials during a perceived crisis in 1982 concerning the use of insulin pumps, CDC established a short-term surveillance system to determine the frequency and severity of complications associated with these devices (133). Using physician reporting, the investigators identified previously unrecognized adverse events associated with pump use as well as 35 deaths among pump users. The data were used to assist the American Diabetes Association in developing a policy statement for clinicians that included new criteria for initiating pump use (134).

Public health surveillance of technology use provides a mechanism for monitoring the use of a practice or device and, together with data on morbidity and mortality, provides an ongoing measure of its effectiveness and safety in the populations being monitored. Surveillance will also indicate whether an effective technology is being applied to the population that is likely to benefit from such technology. It is not known, for example, whether the women undergoing mammography are those most likely to benefit from screening.

The need for surveillance of technology use is evident, but the process of gathering the primary data is not established currently for most technologies other than drugs—the latter being a responsibility of the Food and Drug Administration. As illustrated by the surveillance of tubal sterilization, some hospital data sets can be helpful in tracking inpatient procedures. There is a lack of state and national surveillance information, however, to track diffusion of technologies in the outpatient setting, where complex and expensive technologies are being used increasingly (135).

Although surveillance is usually undertaken by public health agencies at the local, state, and federal levels in collaboration with the medical community, efforts to establish surveillance systems at all levels have faltered in recent years. In its lead federal role in health care technology, the National Center for Health Services Research and Health Care Technology Assessment should be encouraged to develop priority-setting criteria for bringing technologies under surveillance and subsequently for analyzing the impact of technologies in terms of their effect on morbidity, mortality, disability, and cost.

NEW TOOLS FOR PUBLIC HEALTH SURVEILLANCE

Computers

The introduction of computer hardware and software has provided public health professionals with the capability to perform surveillance more efficiently on common conditions. Large data bases may be better managed and analyzed, and in some instances may be linked. In addition, the microcomputer has empowered the public health professional with an increased ability to organize, communicate, tabulate, and analyze data. Use of the computer has increased the timeliness of both data collection and analysis and has decreased the epidemiologist's reliance on programmers

and biostatisticians for data analysis and interpretation.

The Public Health Foundation initiated an electronic mail system in 1983. Several federal health agencies, including CDC, and 44 state health departments are now online. In addition, three states have enrolled their local health departments and can telecommunicate with them. In 1984, this network was used in six states to pilot-test the transfer of notifiable infectious disease data weekly to CDC (136). By early 1988, 37 reporting areas were transferring individual case data on over 40 notifiable diseases to CDC each week. The ability to transfer binary file will allow the telecommunication of graphics, which facilitates review of aggregate data. Surveillance at the state level has been hampered by a lack of microcomputer software for managing and analyzing large numbers of disease records. Currently, software developed for use in epidemic investigations has been adapted for surveillance and used in 20 states (A. Dean, CDC, personal communication, 1987). Use of such software in Georgia has enabled early detection of an epidemic of illness due to *Salmonella havana*, facilitating efforts to identify the environmental source of the organism (137).

Programs at CDC for vaccine-preventable diseases, tuberculosis, AIDS, and diabetes have also developed computer networks with state health departments to enhance their surveillance capabilities. In addition, state health departments have initiated computer linkage with selected local health departments for disease reporting (138). In Wisconsin, for example, case data from sexually transmitted diseases clinics are telecommunicated to each other and to local and state health departments, improving the efficiency of follow-up of patients (A. Dean, CDC, personal communication, 1987).

Use of microcomputers has also expanded surveillance activities to nontraditional reporting sources. Computers in medical examiners' offices will aid in injury surveillance (139); microcomputers in a national sample of hospitals currently aid in collecting information on nosocomial infections (140).

Statistical methods

The increased sophistication of statistical methods, the availability of computers, and the development of statistical software for analysis have broadened the potential of statistical analysis in day-to-day public health practice and have led to the investigation of new methods of data analysis. The usefulness of time series analysis (45), of detecting clusters of adverse health events in time and place (141–144), and of mathematical models to forecast epidemics based on surveillance data (145) remains to be fully assessed.

Although detecting temporal and spatial clusters of disease has always been a goal of public health surveillance, formal statistical testing for clusters has rarely been applied to routinely collected surveillance data. The statistical problems associated with determining whether an "outbreak" has occurred were addressed in depth in the 1960s, and a variety of alternative analyses were proposed. Two commonly used methods for space-time clustering, proposed by Knox and Lancashire (143) and by Ederer et al. (146), are based on the number of "close" pairs of cases and the sum, over all space divisions, of the maximum number of cases in any time unit within a space division. For example, Ederer et al. employed a summary statistic to detect both clusters of leukemia over time and outbreaks of polio and hepatitis.

The SCAN statistic, based on such summary statistics as those used by Mantel (144) and Ederer et al. (146), was proposed by Naus (147) and has recently been applied to a cluster of trisomies in three New York City hospitals (148). This statistic is computed by plotting points over time, taking a "moving window" of a fixed length of time, and then finding the maximum number of observations revealed through the window as it scans or slides over the entire time period. The statistic is based on the

assumption that the size of the population at risk remains fairly constant and that the condition shows no seasonal or cylical pattern over the time period plotted. Other analytic methods have been suggested for using environmental data to predict the occurrence of Rocky Mountain spotted fever, but such methods have not been used routinely (142).

The Chandra Sekar-Deming method developed by demographers has been used to estimate completeness of reporting by comparison of two independent surveillance systems with individual identifiers so that the data may be linked (149). This method has recently been applied to AIDS data reported through the notifiable disease system and through death certificate registration (150). It has also been applied to estimate the sensitivity of two systems for detecting vaccine-preventable diseases (151).

Surveillance systems are subject to both selection and information biases. Notifiable disease reports, for example, are likely to come from a nonrepresentative sample of practicing physicians who may report specific diseases because of personal interest. Private practitioners, for example, may be less likely than physicians at public health clinics to report certain conditions (e.g., sexually transmitted diseases). At the same time, certain kinds of data are less likely to be reported than others because of ease of ascertainment (e.g., age or sex vs. pathologic diagnoses). Analytic models are required to measure the impact of bias on surveillance data. Other important research issues on the statistics of surveillance include the development of methods to handle incomplete or missing data, the use of multiple subset sampling, modeling of timeliness, and the combination of data from independently collected data sets.

Graphic methods for data analysis and display

Graphics have the potential to serve as powerful tools for displaying data both for analysis and for communication. Tukey (152) has clearly demonstrated the important role graphs can play in visual decoding of large quantities of data. Although Tukey's methods have not yet been widely applied to surveillance data, his pioneering work together with the introduction of computer graphics has laid the foundation for graphic analysis of surveillance data (153). Microcomputer graphics, in particular, have also made the results of data analysis far more useful to private and public policymakers in their planning and management of health care resources (35). Although simple data still are incorporated best into textual material or a tabular format, a graphic display can give the reader an understanding of large and complex data sets that cannot be conveyed easily in other ways (154).

The interest in computer mapping in public health is strong. A 1976 workshop sponsored by NCHS featured several applications of automated cartography to epidemiology (155). In the area of surveillance, mapping of disease rates by county, sex, age, and race based on large computerized data sets first proved its usefulness when the cancer atlases were developed by the National Cancer Institute in the 1970s (76). The Environmental Protection Agency has also produced maps on cancer (156). Injury maps have been used to convey visually the race- and sex-specific differences in rates of various injuries (157). Although it has been common practice to plot individual cases or rates of disease on geopolitical maps, population-based maps have been produced to account for population size. More recently, exploded population maps have been considered for use in surveillance. These maps are developed by the isomorphic reduction of geographic entities in relation to the entity with the greatest population density, with or without an overlap of the geopolitical map (158). Other mapping of surveillance data for programmatic use has included the development of probabilistic contouring, with maps demonstrating the estimated probability of a health event or an exposure, a technique

that has proven particularly useful in program planning (159).

Limitations in the Practice of Surveillance

The variety of uses of public health surveillance is not widely appreciated. For some, the concept of surveillance is limited to reporting notifiable communicable diseases to state and local health departments. Others think in terms of laboratory- or hospital-based surveillance, particularly for nosocomial infections. Another interpretation is seen in recent legislation establishing the Agency for Toxic Substances and Disease Registry, which limited health surveillance to medical screening of individuals (160).

Other perspectives limit the potential scope of public health surveillance. The most common is that surveillance is limited to data collection and collation. It is important for a system of public health surveillance to include analysis and interpretation of data, as well as dissemination of those data to the relevant persons. Finally, to be complete, a public health surveillance system requires linkage to programs. When this broad perspective is not understood, the practice of surveillance and of epidemiology in public health is constrained short of its potential.

Inexperience with surveillance methods

Except in state and local health departments, relatively few persons have been involved in a complete program of public health surveillance. Most persons are involved with only one portion of a surveillance system (e.g., data collection) or with only a limited array of health events (e.g., communicable diseases). The lack of familiarity with public health surveillance is even more pronounced in medical schools and schools of public health, where it is rarely discussed and is almost never the subject of careful analysis. Textbooks of epidemiology and public health are similarly remiss in addressing the scope of public health surveillance, with few texts devoting even a chapter to the subject (161, 162). The only substantive training for surveillance in the United States is as part of the actual practice of public health. The public health community is only now beginning to approach surveillance in a more scientific manner, looking beyond case counting and simple descriptive epidemiology. Sophisticated statistical tools such as time series analysis (45) and the SCAN statistic (148), for example, have been applied successfully to surveillance data. Expansion of public health into new fields such as chronic disease demands more rigorous scientific scrutiny of surveillance methods as well as different approaches to public health epidemiology (52). To date, however, the communities of both health care providers and teachers of medicine, nursing, and public health remain uninformed about needs in public health surveillance. Their involvement, in the future, could contribute significantly to the practice and development of public health surveillance.

Data gaps

Even in communicable disease reporting, data are often incomplete, unrepresentative, and untimely. Depending on the severity and perceived importance of a disease, rates of reporting notifiable diseases have been estimated to vary from 6 per cent to 90 per cent (54, 163–165). Both measles and AIDS programs, for which many resources have been targeted toward surveillance efforts, attain greater than 90 per cent sensitivity (150, 166). In a study of *Shigella* surveillance in Washington, DC, however, investigators found that persons with disease were more likely to be reported if they were treated by private physicians—a practice that leads to unrepresentative surveillance data (55). Efforts to improve the quality of reporting have been shown to have some effect—improving sensitivity at the local level as much as ninefold for selected acute infectious diseases—but the ultimate impact of such improvements in surveillance remains to be assessed in terms of

improved health and reduced cost (56, 57, 64, 167).

Surveillance in rapidly evolving areas of public health, such as injuries and chronic diseases, often relies on existing data sets, because of the usefulness of historical data and the prohibitive costs of new systems (167). Evaluation of the use of such data sets for public health surveillance represents an important new challenge.

Policy

Effective public health practice requires the following: 1) an accurate assessment of the public health; 2) definition of specific public health priorities; 3) development and implementation of research and control programs to improve health; and 4) an evaluation of these programs (2). Public health surveillance data can provide a quantitative basis for policy decisions and allocation of scarce resources. Furthermore, the information gained from surveillance programs can significantly contribute to the continuous redefinition of public health priorities as problems are resolved and other needs emerge. In short, good surveillance data can and should be used to guide public health practice.

Policy should be based on accurate data. The quality and limitations of both surveillance data and their interpretation must be recognized by those communicating the information and by those establishing policy. Ideally, policymakers, in responding to questions related to health policy, will know to turn to the surveillance program.

Similarly, public health surveillance should not be seen as an end in itself, but rather as a tool for use in promoting health and preventing and controlling disease and disability. Surveillance data should not be acquired at the cost of privacy, nor should the quest for precise numbers or exquisite analyses lead to costs that outweigh the benefits of such information to the public health. Again, the need for data must be kept in perspective in relation to their intended use.

CONCLUSIONS

Public health surveillance provides a quantitative basis for other distinct facets of public health practice, including epidemiologic research and control and prevention services. Public health surveillance includes not only data collection and analysis but also the application of these data to control and prevention activities by disseminating information to practitioners of public health and others who need to know. Although surveillance has been conducted in some form for more than a century, its uses and practices have evolved most dramatically over the past 40 years. A significant change has been the extension of surveillance beyond infectious disease to include the spectrum of public health problems in chronic disease, occupational health, injury, the environment, personal behaviors, and preventive health technologies. A second significant change has been the effort to put public health surveillance on a more quantitative basis.

Public health surveillance has been perceived by most as an early warning system, a crude indication of the occurrence of unusual disease patterns. Because of a focus on timeliness and simplicity, there has often been less concern for data quality. In recent years, however, there has been an increased use of data obtained outside of public health practice and a concomitant increased concern with the quality of surveillance data and methods used to collect and analyze these data (51). It is appropriate, therefore, for the epidemiologist to examine this tool carefully and to ascertain how one can efficiently improve the collection, analysis, and dissemination of surveillance data. In other words, application of a scientific approach to this method should improve its usefulness.

Several current activities will have a significant impact on the practice of public health surveillance. We need to identify data sets relevant to specific health problems in the most rapidly evolving areas of public health. In some cases, this will re-

quire creating new data sets such as the Behavioral Risk Factor Survey, which is jointly conducted by CDC and state health departments (62). More often, ongoing data collection efforts, such as the notifiable disease data systems maintained by state health departments, and data surveys conducted by NCHS, will be adapted to surveillance needs. Statistical and graphic techniques will improve utilization and understanding of available data. Computers will play an increasingly large role, not only in analysis but also in graphic display methods and electronic data dissemination.

The critical challenge in public health surveillance today, however, remains the ensurance of its usefulness. For this purpose, therefore, we need regular, rigorous evaluation of public health surveillance systems. Even more basic is the need to regard surveillance as a scientific endeavor. To do this properly, one must fully understand the principles of surveillance and its role in epidemiologic research and other aspects of the overall mission of public health. What is necessary now is to develop the epidemiologic methods relevant to public health surveillance; to apply computer technology for efficient data collection, analysis, and graphic display; to apply surveillance principles to practice; and to routinely assess the usefulness of surveillance systems.

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