How Outbreaks of Infectious Disease are Detected: A Review of Surveillance Systems and Outbreaks

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SYNOPSIS

To learn how outbreaks of infectious disease are detected and to describe the entities and information systems that together function to identify outbreaks in the U.S., the authors drew on multiple sources of information to create a description of existing surveillance systems and how they interact to detect outbreaks. The results of this analysis were summarized in a system diagram. The authors reviewed a sample of recent outbreaks to determine how they were detected, with reference to the system diagram. The de facto U.S. system for detection of outbreaks consists of five components: the clinical health care system, local/state health agencies, federal agencies, academic/professional organizations, and collaborating governmental organizations. Primary data collection occurs at the level of clinical health care systems and local health agencies. The review of a convenience sample of outbreaks showed that all five components of the system participated in aggregating, analyzing, and sharing data. The authors conclude that the current U.S. approach to detection of disease outbreaks is complex and involves many organizations interacting in a loosely coupled manner. State and local health departments and the health care system are major components in the detection of outbreaks.

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Prompt detection of an outbreak of infectious disease may lead to control measures that limit its impact and help prevent future outbreaks.[1–7] In the United States, the current approach to outbreak detection is complex—involving private and public entities under local, state, national, and international jurisdictions. Some complexity can be traced to Amendment 10 of the Constitution, which reserves for the states all powers not delegated to the federal government, including protection of the public's health.

A description of the complex U.S. approach to outbreak detection would facilitate analysis and research by focusing attention on data flow and other issues. We have compiled information about current systems and summarized the relationships among the systems diagrammatically. In the present article, we illustrate the analytic use of this diagram of the system by examining, for a sample of outbreaks, how and how quickly they were detected, with reference to the diagram.

EXISTING U.S. SYSTEMS FOR OUTBREAK DETECTION

In 2001, we compiled an initial list of infectious disease surveillance systems in the U.S. by: (*1*) searching the websites of the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO); (*2*) reviewing literature published from 1993 to 2000 that was cited in the HealthSTAR database; (*3*) searching Google.com using the phrases "bioterrorism and public health" and "infectious disease surveillance"; and (*4*) searching all reports of infectious disease outbreaks in volumes 48 and 49 of the *Morbidity and Mortality Weekly Report* (*MMWR*) for mentions of surveillance systems that contribute to the detection of outbreaks.

For each system mentioned, we collected the system type, data origin, data type, disease scope, geographic scope, main partner, and a reference to a website or article for additional information.

To identify additional surveillance systems, we posted the results of the above process on the Internet at www.cphp.pitt.edu/detection and e-mailed a request for additions and corrections to members of the Council of State and Territorial Epidemiologists (CSTE) using its listserv.

Our request for assistance to state and territorial epidemiologists resulted in the identification of one additional system—the Rapid Syndrome Validation Project—and one minor correction to our description of the National Electronic Telecommunications System for Surveillance (the change was the reclassification of the main partner from the CDC to local and state health departments). The total process identified 66 detection systems, which are described elsewhere in detail.[8,9]

We next analyzed the interactions among the many systems on the list by diagramming the flow of data based on information collected about the systems and the direct field experience of one author (VD) with six years of outbreak investigation experience in two states. This first diagram, which contained 20 distinct elements, is available on the Web[8] (p. 25). We developed a simplified version of the diagram by categorizing the main partner in each system into one of four categories (state, federal, academic/professional, collaborating governmental organization) and adding a fifth category, the clinical health care system, from which much of the data originates (Figure).

The Figure shows the results of the analysis of the 66 surveillance systems and how they relate to each other for the detection of outbreaks as a de facto U.S. outbreak detection system. At the center of the diagram is the state (which includes local public health agencies). The other components are the clinical health care system, the federal government, academic/professional organizations, and collaborating governmental organizations.

The *Clinical health care system* (non-government hospitals, physicians, pharmacists, and laboratories) is the entity that most often provides the data on which detection and characterization rely. Some data collection is mandated by law; clinicians and health care entities are required to report specific diseases to public health authorities.[10] The statutes covering reportable disease often require that unusual manifestations or unusual numbers of ill individuals also be reported. Voluntary primary data collection occurs when physicians and hospitals (as part of sentinel or surveillance networks) collect specialized data and/or submit specimens for specialized tests. Primary data collection also occurs at the *Local public health agency* level. Public health workers see patients in public health clinics and collect additional information from ill individuals after receipt of reports from the clinical health care system. Local health agencies also receive information from individuals who wish or are required to report the possibility of an outbreak.

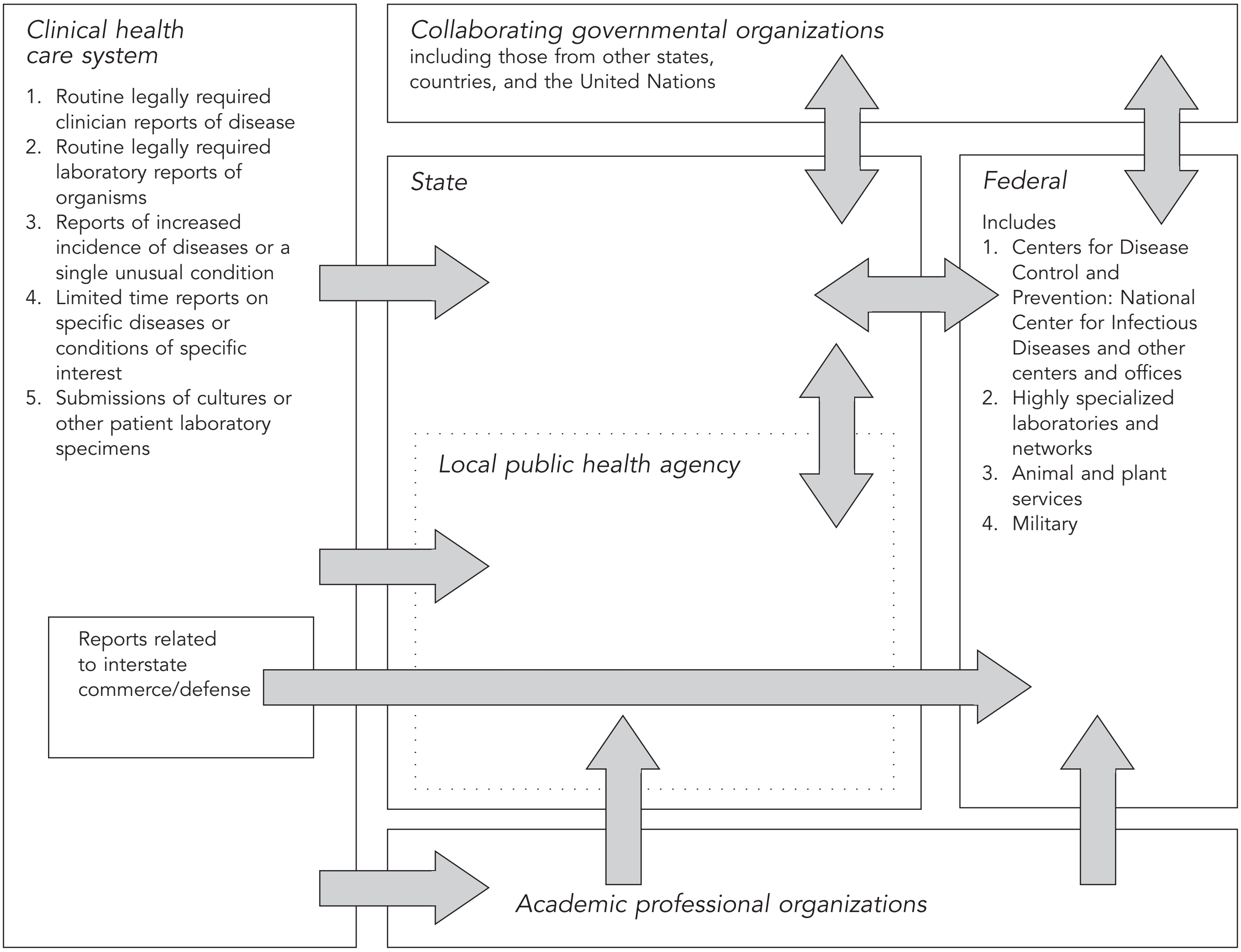
The outbreak detection function may be performed by a front-line clinician, if the clinician sees multiple cases and makes the association or if a single case (e.g., measles) is sufficient to raise an alarm. For many types of outbreaks (e.g., *Salmonella*), however, detection requires central aggregation and analysis of cases. These types of outbreaks can be detected by three other components (local/state health agency, academic/professional organizations, and the federal government).

The *State* is the primary entity with the authority for case aggregation and pattern detection due to police powers reserved for the states by Amendment 10 of the Constitution. Police powers include the right of the state to require the reporting of confidential information and powers such as quarantine needed to respond to an outbreak. The actual use of police powers depends on the state's constitution, regulations, and customs. We refer to the entity that accepts, aggregates, triages, and investigates infectious disease reports as the *Local public health agency*. This agency derives its police powers from the state but can be administered by municipal, county, or state government; great variation exists within and among states.

Data are submitted to the local public health agency from the clinical health care system in a variety of ways. Reports can be submitted via phone calls or faxes, or via electronic data exchanges. Data can be submitted individually in real time, or in large batches. As already noted, additional data may be received from individual citizens. These reports are eventually de-identified and sent to the CDC through the National Electronic Telecommunications System for Surveillance (NETSS),[11] where they are aggregated

Figure. De facto U.S. outbreak detection system

The clinical health care system and local public health agencies are responsible for most primary data collection. Local public health agencies are also responsible for aggregation, triage, and investigation. Other entities including the federal government and academic/professional organizations have roles in data collection and analysis. Collaborating government jurisdictions share the results of data analyses.



on a national basis. The process of collecting and transmitting data is being standardized through the National Electronic Disease Surveillance System (NEDSS).[12]

The *Federal* component in the Figure depicts the role of the federal government in outbreak detection. Part of this role is defined by the U.S. Constitution, in the event that outbreak detection is needed for the defense of our country against bioterrorism or as part of the regulation of interstate commerce (e.g., federal inspections of meat products sold in interstate commerce). The federal government also contributes to outbreak detection by providing specialized research networks, specialized experts, and advanced laboratories. Some information and specimens are collected directly from the clinical health system and the public (through institutional review board–approved research), but most of the data come from the state health departments after deidentification.

Among the federal systems for the detection of outbreaks are the Foodborne Disease Outbreak Surveillance System,[13] the CDC Unexplained Deaths and Critical Illness Surveillance Project,[14] and the CDC National Botulism Surveillance and Reference Laboratory.[15]

The bottom box of the Figure is devoted to *Academic/professional organizations* and, rarely, commercial institutions with research or public service–related surveillance activities. Examples are ProMED (International Infectious Disease Society),[16] the Indianapolis Network for Patient Care (Regenstrief Institute for Health Care),[17] and the Real-time

Outbreak and Disease Surveillance System (University of Pittsburgh).[18,19]

The top box of the Figure is devoted to *Collaborating governmental organizations*. These can be another local or state health department, a public health agency of another country, or the World Health Organization (WHO), the United Nations specialized agency for health. Public health workers in different jurisdictions frequently communicate both formally and informally about outbreaks occurring in their jurisdictions and about potentially infected individuals traveling between jurisdictions. This communication and data sharing is necessary because infectious disease outbreaks do not respect governmental boundaries. Exchange of information can be via direct communication between two health jurisdictions on an as-needed basis; however, specialized communications networks also exist. Examples of programs that can assist local health districts by providing information about disease in other entities include the Global Outbreak Alert and Response Network,[20] WHONET (an information system for monitoring antimicrobial resistance),[21] the WHO collaborating laboratories,[22] and the Global Public Health Information Network.[23]

OUTBREAK DETECTION IN PRACTICE: ANALYSIS OF A CONVENIENCE SAMPLE OF OUTBREAKS

We obtained a convenience sample of 51 outbreaks by reviewing volumes 48 (1999) and 49 (2000) of the *MMWR* for reports of outbreaks of infectious disease (excluding nosocomial infections) that occurred in the U.S. We defined an outbreak as two or more cases of a disease clustered in time or place. For each outbreak, we determined how the outbreak was first detected using information provided in the *MMWR* report. When an article specified that individual cases were reported to the health department, we classified the outbreak as having been detected by the health department through an aggregation of individual reports. When possible, we calculated the time to detection using as the starting point the reported date of onset of illness in the first individual. We also grouped the outbreaks into previously described detection categories[24] with one modification—we split the commercial product category into "commercial distribution" and "foodborne (noncommercial)" categories. The rationale for this modification was that we found reports of a number of foodborne outbreaks that occurred in noncommercial settings (U.S. Army, schools) or that did not appear to be linked to commercial food distribution.

Our survey of *MMWR* articles found 51 outbreaks,[25–61] of which 43 (84%) had sufficient information to allow classification of how they were detected (see Table). Health department staff detected the outbreak from aggregation of clinical or laboratory reports in 23 (53%) of these outbreaks. Twelve (28%) were reported as suspected outbreaks to the local health agency; of these, three were reported by the clinical health care system (all through astute clinicians),[29,47,59] three by school health services,[38,56] one by a correctional health service,[60] one by a worksite,[41] and four by an unspecified party.[37,53,58] Two, including one rubella outbreak, were first detected at public sexually transmitted disease clinics.[33,36] Overall, in 37 (86%) outbreaks, detection involved the local public health agency level.

Federal networks of laboratories performing advanced testing and analysis of specimens detected three outbreaks (one *Listeria*, two drug-resistant gonorrhea)[44,54] and found additional cases in multiple states in three outbreaks initially detected in a limited number of locations.[27,37,57] Two of the three multistate outbreaks involved widely distributed products (parsley[37] and orange juice[57]), and one involved an interstate social network.[27] An Army unit detected one Norwalk-like outbreak when 99 out of 835 soldiers were hospitalized.[58] Thus federal involvement was crucial in the detection of four outbreaks and led to detection in additional states in three other outbreaks.

The collaborating government and academic/professional components in our diagram contributed to the detection of one outbreak each. In one situation, a notification from national public health agencies in several European countries of cases of serogroup W-135 meningococcal disease among pilgrims returning from the Hajj in Mecca and their close contacts helped local health departments to detect serogroup W-135 meningococcal infections.[42] In the other, a university laboratory notified local health officials of a positive test for anthrax in a steer, which led to detection of gastrointestinal anthrax infections in humans on a Minnesota farm.[61]

Although the clinical health care system directly detected just three of the outbreaks, disease reports and clinical laboratory specimens generated by the clinical health care system were necessary in 31 (72%). The only outbreaks in which the clinical health care system was not involved were those picked up in governmental settings (e.g., STD clinics,[36,45] the military,[58] and prison[60]), schools,[38] and a business.[41]

Information on the time to detection was available for 21 (41%) of the 51 outbreaks (Table). Nine (42%) of 21 were detected within one week of the first case (five of the nine were detected within two days). Six (29%) were detected between one week and one month, and six (29%) were detected after a month or more. Outbreaks caused by organisms with short incubation periods and in which individuals were not widely dispersed had relatively short times to detection. Outbreaks caused by organisms with long incubation periods and/or in which contaminated products (especially commercially distributed products) or the people they infected were widely dispersed took the longest to detect.

EMERGING INFECTIONS

Outbreaks caused by previously unidentified organisms (a subset of emerging infectious diseases) were not represented in the 51 outbreaks just discussed. We used a CSTE position paper[62] and our experience to identify five diseases in this category for special study: Lyme disease, *Legionella* disease, AIDS, hantavirus pulmonary syndrome, and severe acute respiratory syndrome (SARS).

In 1975 in Lyme, Connecticut, two mothers recognized that the number of juvenile rheumatoid arthritis cases in their community seemed too high to be due to chance. An academic researcher (at the request of the local health department) figured out that the affected children did not

Table. Number of outbreaks by detection category,[24] organism, and time to detection (*N*=51 outbreaks)

Detection category and organism	*<2 days*	*>2 days <1 week*	*>1<4 weeks*	*1–2 months*	*>2 months*	*Missing data*
Contagious person-to-person						
Influenza A						1
N. meningococcus						1
Rubella virus			1			2
Varicella-zoster virus				1		
M. tuberculosis				1	2	1
Group A streptococci	1					
Methicillin-resistant *S. aureus*						1
Continuous release						
Coccidioides immitis						1
Blastomyces dermatidis			1			
Enclosure (building/ship) contamination						
Norwalk-like virus (norovirus)	1					
Foodborne (noncommercial)						
E.Coli		1				1
Rotovirus		1				
Bacillus anthracis (anthrax)						1
Norwalk-like virus (norovirus)	1	1				
Unknown etiology	2					
Commercial distribution						
Shigella						5
Salmonella			2			4
Listeria					1	
Vibrio parahaemolyticus				1		
Sexual or parenteral transmission						
HIV						2
N. gonorrhoeae						2
Small premonitory release or contamination						
Legionella pneumophilia						1
Basidiobolomycosis						1
Arenavirus						1
Vector/host-borne						
West Nile virus			1			
Plasmodium vivax		1				
Salmonella						2
Waterborne						
E. Coli, Campylobacter						1
Shigella sonnei,						
Cryptosporidium parvum			1			
Pseudomonas						2
Total	5	4	6	3	3	30

have rheumatoid arthritis, but a new disease. The causative organism for Lyme disease was not discovered until 1981 by a federal laboratory.[63,64]

On a Sunday in the summer of 1976, an American Legion official notified the Philadelphia Department of Public Health that in the past week he had gone to eight funerals of veterans—all recent attendees of the State Chapter convention in Philadelphia (Personal communication, Lewis D. Polk, MD, MPH, former Commissioner, Philadelphia Department of Public Health, February 2004). An intensive investigation involving a national effort pointed to one hotel used by attendees at an American Legion convention. The etiologic agent of the newly named Legionnaire's disease was finally isolated at the CDC in early 1977.[65]

In San Francisco in 1981, researchers at a the Mount Zion Hospital and Medical Center and the San Francisco Department of Public Health reported an "extraordinarily high rate of CMV infections,"[66] a CDC drug technician noted an increase in pentamadine requests, and other physicians noted increases in *Pneumocystis carinii* pneumonia and Kaposi's sarcoma cases.[67] The organism causing AIDS was not identified until 1984.[68]

In May 1993, medical personnel at the Indian Health Service (IHS) discovered that a Navajo man and his fiancée had died with similar symptoms within one week of each other. After a few hours of phone calls, an IHS physician, working with the New Mexico Office of Medical Investigations, uncovered five instances of recently deceased, previously healthy, young people. By November 1993, after efforts by three state health departments, three federal agencies, the Navajo Nation, and a university, a new virus eventually called the Sin Nombre virus was identified as the cause of this new disease entity, hantavirus pulmonary syndrome.[69]

On February 10, 2003, ProMED carried an e-mail message from a physician asking about a rumor transmitted through a chat room reporting hospital closures and dying people in Guangzhou, China.[70] On February 28, a WHO infectious disease specialist consulted on an unusual case of pneumonia in Hanoi, Vietnam. By March 10, 22 hospital workers in Hanoi were ill with a similar illness.[71] On March 12, WHO issued an unprecedented global alert about cases of atypical pneumonia in Vietnam, Hong Kong, and China.[72] This alert resulted in the detection and containment of the virus in numerous countries across the world. By April 17, a truly international effort on the part of the medical community, universities, and national governments had resulted in the isolation and demonstration of a novel coronavirus as the cause of severe acute respiratory syndrome (SARS).[73]

All of these outbreaks came to the attention of the public health community through astute individuals who recognized a change in patterns of disease or evidence of a new organism and had the foresight to report their observations. However, these individuals did not and could not know what they had detected. Determining the "what" required intensive resources of the U.S. government, professional and academic institutions, and other collaborating governmental organizations.

CONCLUSION

The Figure describes the relationships among five components of the outbreak detection system: the clinical health care system (non-government hospitals, physicians, pharmacists, and laboratories), local/state health departments, the federal government, academic/professional organizations, and collaborating governmental organizations. The current U.S. approach to detection of disease outbreaks is complex and involves many organizations interacting in a loosely coupled manner. We have demonstrated the value of an explicit understanding of this complexity for analyzing outbreaks. This diagram is a simplification of the highly distributed de facto outbreak detection system in the U.S. Detailed information about the many different subcomponent surveillance systems can be found at www.cphp.pitt.edu/detection/systems.htm.[9]

Our review of a sample of outbreaks shows the importance of the clinical health care system and local/state public health agencies for outbreak detection. This review also emphasizes the heterogeneity of ways that outbreaks are currently detected, with the most common being aggregation of reportable diseases by health departments and reports of suspicious clusters and/or unusual diseases by clinicians and lay individuals.

Newly emerging infections present special challenges because they cannot be added as reportable diseases or routinely studied in specialized networks until after they are first detected. It is not a surprise that astute individuals have played the major role in the detection of emerging infections.

The generalizability of our analysis is limited by the use of a convenience sample of outbreaks. Moreover, the analysis was limited to interpretation of published information about those outbreaks. Therefore, the main conclusions should be qualitative, rather than quantitative, conclusions that the current system detects outbreaks in diverse ways, that many outbreaks are first detected by individuals outside of "formal" surveillance systems, and that many outbreaks are detected after very long delays (exceeding weeks to months).

Our description of a sample of outbreaks is consistent with the results of Ashford and associates in a study of outbreaks caused by agents with bioterrorism potential.[74] Using a different categorization, they found that the initial reporters of outbreaks to the CDC were health care providers (24.6%), infection control practitioners (11.7%), health departments (30.5%), existing surveillance systems (5.0%), foreign ministries of health (2.7%), nongovernmental organizations (2.0%), the WHO (1.5%) and the IHS (1.1%).

The recent SARS outbreak provides a concrete example of the importance of all five components in the early detection of outbreaks. In the SARS outbreak, the infectious agent spread around the world at the speed of airplanes, but information spread faster. The large number of infections that resulted from a few index cases in Hanoi, Hong Kong, Singapore, and Toronto would have been replayed in numerous countries had it not been for prompt communication and resulting public health investigations and control measures.

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