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# Surveillance and investigation of foodborne diseases; roles for public health in meeting objectives for food safety

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**Abstract**

Each year, an estimated 76,000,000 persons experience a foodborne infection in the United States. Preventing foodborne infections requires sustained efforts along the entire chain of production. Public health surveillance drives a number of disease prevention programs, including tuberculosis control, polio eradication, and foodborne disease prevention. CDC has launched several new approaches to foodborne disease surveillance, including FoodNet, PulseNet, and the National Antimicrobial Resistance Monitoring System for Enteric Bacteria (NARMS). The capacity of public health surveillance in the United States to detect and investigate dispersed foodborne disease outbreaks has been improving dramatically in recent years. Investigation of such outbreaks can yield important insights in how to improve prevention strategies. Many foodborne diseases are preventable, though prevention will require a number of control efforts along the chain from production to consumption. Although progress has been made to date as a result of recent improvements in food safety, further prevention efforts are required in the United States if we are to reach the public health objectives set for 2010.
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*Keywords:* Foodborne diseases; Public health surveillance; Antimicrobial resistance; Foodborne disease outbreak

## 1. Introduction

Each year, an estimated 76,000,000 persons experience a foodborne infection in the United States, 325,000 are hospitalized, and 5000 die (Mead et al., 1999). The annual patient-related costs of just the principal bacterial and parasitic foodborne infections have been estimated at $6.5 billion or more (Buzby & Roberts, 1996). To this can be added lost wages, product recalls, and other social costs. Among the established foodborne infections, bacterial infections account for an estimated 30% of cases, 63% of hospitalizations and 72% of deaths; viral infections account for 67%, 35% and 7%, respectively, and parasitic infections account for 3%, 5% and 21%. Five foodborne pathogens – *E. coli* O157:H7, *Salmonella*, *Campylobacter*, *Listeria*, and *Toxoplasma* – together cause an estimated 3.5 million cases, 33,000 hospitalizations and 1600 deaths each year.

Preventing foodborne infections requires sustained efforts along the entire chain of production. Despite substantial research, effective vaccines are not available for the great majority of infections. Educating the consumer is important, but not sufficient, as many foodborne diseases are the result of contamination of foods that may not be well cooked themselves, or that is beyond the control of the consumer. Foods can be contaminated with microbes, and the number of microbes present may be amplified at many points from growing or rearing on the farm to processing to final preparation. Understanding those mechanisms of contamination is critical to interrupting them, and thus preventing the infection from reaching the consumer. Detailed epidemiologic investigations of how contamination occurs in outbreak settings can identify such points of contamination, and thus target the development of improved control strategies. Effective control of many foodborne infections ultimately depends on designing food production and processing for safety.

A broad menu of options is available for improving the prevention and control of foodborne diseases. At the producer level, improving on-farm sanitation and biosecurity, competitive exclusion, prudent antimicrobial use, and other good agricultural practices can be strengthened. At the processor level, verifying that food

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processing is microbiologically sound, adopting hazard analysis-critical control point (HACCP) strategies, and controlling contamination and temperature during transport and storage are important. In the kitchen, foodhandler training and certification, handwashing, and provision for ill workers could prevent many illnesses. Definitive pathogen elimination technologies, such as pasteurization and irradiation can prevent many infections (Tauxe, 2001).

Public health surveillance drives a number of disease prevention programs, including tuberculosis control, polio eradication, and foodborne disease prevention. Surveillance is the systematic collection of reports of specific health events as they occur in a population. This monitoring is linked to action. Surveillance defines the current magnitude and burden of a disease for which prevention measures are planned or in place. It identifies unusual clusters, or outbreaks of the disease, so that actions to control them can be taken. Surveillance also measures the impact of control and prevention efforts, and it serves to reassure the public that this critical part of public safety is in place. The process can be conceived of as an iterative loop (Fig. 1). Surveillance may identify an increase in the frequency of a disease, thus triggering an epidemiologic investigation. That investigation may identify immediate control measures that can be implemented, and it may also identify areas in need of applied research so that better control measures can be developed. Once control measures are taken, it is surveillance that will demonstrate that the immediate problem is controlled.

In the United States, basic public health surveillance takes place in every county and State. Clinicians report notifiable diseases to the county health departments, clinical laboratories report specific diagnosed infections, and for *Salmonella* and *Shigella*, bacterial strains isolated from human specimens in clinical laboratories are referred by the clinical laboratories to the city or state public health laboratories for serotyping. The results of that serotyping, and the surveillance information on many conditions, are examined at each level, and are transmitted to CDC. Local foodborne and waterborne outbreaks are investigated and reported to CDC by local public health authorities.

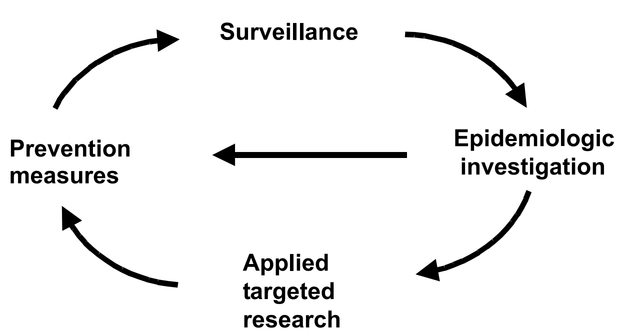


Fig. 1. Surveillance drives the cycle of public health prevention.

Public health surveillance in the United States began with cholera in the 19th century. Early in the 20th century, national statistics begin to be collected for a range of conditions, including typhoid fever (Fig. 2). The incidence of typhoid fever dropped sharply through the first third of the century as pasteurization of milk, treatment of sewage and drinking water, and improved sanitation of shellfish beds closed the main pathways of transmission for that infection. Successful control was achieved before the antibiotic era without the widespread use of vaccines. Nontyphoidal salmonellosis first began to be reported at the national level in 1942. It rose steadily until the end of the 1980s, when it leveled off; in the late 1990s the incidence rate appears to be decreasing.

Although large foodborne outbreaks tend to attract headlines and focused attention, most foodborne infections occur as individual isolated cases that are not obviously linked to other known cases of illness. These sporadic cases are usually difficult or impossible to attribute to a particular source, as the possibilities are too numerous. Identifying the sources usually depends on study of large numbers of sporadic cases, for instance in an epidemiologic case-control study, or on identifying a group of infections among the sporadic cases that appear to be related, and investigating that cluster intensively. If these sporadic cases represent a great sea of illnesses, then much of the effort of public health surveillance has gone into fishing clusters of related cases from this sea. This is a classic problem of signal to noise, which has been addressed by typing the strains of disease-causing bacteria, or pathogens, in public health laboratories to identify related infections, and by increasing the epidemiologic attention paid to sporadic cases of illness in general.

Since 1962, public health laboratories have serotyped *Salmonella* strains from persons with salmonellosis, a critical subtyping system that greatly enhances the ability to detect and investigate outbreaks of salmonellosis, which are almost always caused by a single serotype. Although the different serotypes of *Salmonella* produce the same spectrum of illness, they have different reservoirs and different specific vehicles of transmission. The three most common serotypes, Typhimurium, Enteritidis and Heidelberg, are common in cattle, egg-laying hens and broilers, respectively, and thus would be controlled by programs with somewhat different targets (Fig. 3).

CDC, in collaboration with state public health departments and the federal food regulatory agencies (including the Department of Agriculture and the Food and Drug Administration (FDA)), has launched several new approaches to surveillance to provide more detailed information for some conditions. These new approaches include FoodNet, PulseNet, and the National Antimicrobial Resistance Monitoring System (NARMS) for

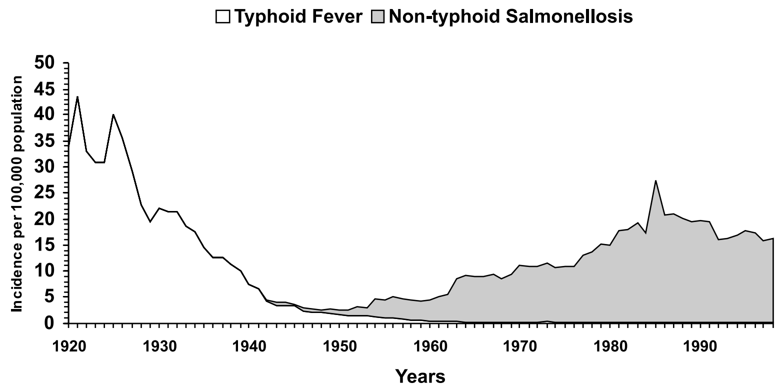


Fig. 2. The fall and rise of reported *Salmonella* infections in the United States, 1920–1998 (National notifiable disease reporting system).

Enteric Bacteria. FoodNet is a network of nine sentinel sites conducting active surveillance for conditions that are often foodborne (Fig. 4), (Angulo & Group, 1997), (www.cdcd.gov/ncidod/dbmd/foodnet/). FoodNet measures the burden of illness, determines the sources of infections through large case-control studies of sporadic cases, and tracks the impact of control measures on these infections. Active surveillance means reaching out to clinical laboratories for information about what they are diagnosing, rather than waiting passively for them to report it. Thus it gives an accurate picture of what is actually being diagnosed at the clinical level. FoodNet also conducts a linked series of studies of the population at large to determine the frequency of diarrheal illness and the likelihood that the ill person would consult a physician and that the physician would order a stool culture. FoodNet surveys clinical laboratories to determine which tests are routinely performed. New pathogens can be added. In 1996, FoodNet conducted a nationwide survey to look for new variant Creutzfeld-Jakob disease, and found none (CDC, 1996). In 1997, the parasitic agents *Cyclospora* and *Cryptosporidium* were added, bringing the total number of pathogens under surveillance to nine. The caliciviruses have not been included in FoodNet surveillance, though they are very common causes of foodborne gastroenteritis, because they are not identified in clinical laboratories.

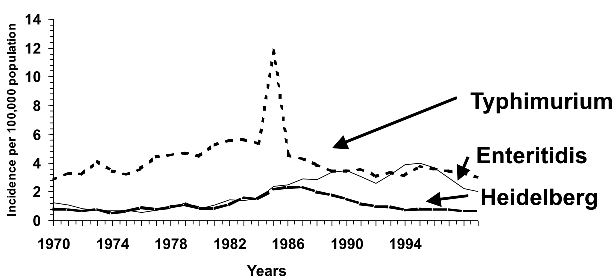


Fig. 3. Reported national incidence of the three most frequent serotypes of *Salmonella*: Typhimurium, Enteritidis, and Heidelberg, United States, 1970–1999 (National *Salmonella* surveillance system).

The surveys and surveillance conducted through FoodNet have helped to given a more precise measure of the impact of these foodborne infections. Like all public health surveillance, the number of reported cases

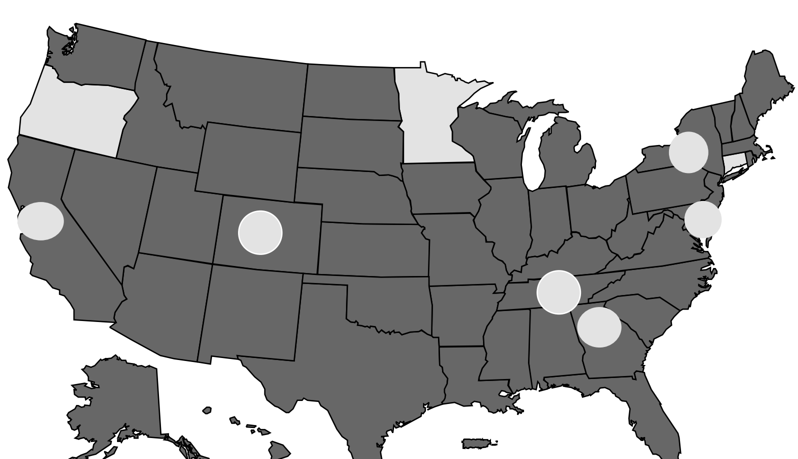

Fig. 4. Foodborne Diseases Active Surveillance Network (FoodNet) participating sites, January 1, 2001. 2000 population = 27 million. FoodNet is a collaboration among these sites, the CDC, USDA and FDA, conducted under the auspices of the Emerging Infections Program at CDC.

Table 1
Annual incidence of selected foodborne pathogens in the original five FoodNet sites, and the comparable Healthy people objectives for 2000 (set in 1988) and 2010 (set in 1998)

| Pathogens | Annual incidence per 100,000 population | | | | Healthy people objectives for | |
|---|---|---|---|---|---|---|
| | 1996 | 1997 | 1998 | 1999 | 2000 | 2010 |
| *Campylobacter* | 23.5 | 25.2 | 21.7 | 17.3 | 25 | 12.3 |
| *Salmonella* | 14.5 | 13.6 | 12.4 | 14.8 | 16 | 6.8 |
| *E. coli* O157:H7 | 2.7 | 2.3 | 2.8 | 2.1 | 4.0 | 1.0 |
| *Listeria monocytogenes* | 0.5 | 0.5 | 0.6 | 0.5 | 0.5 | 0.25 |

of salmonellosis under-represents the whole burden. This happens because many people who are ill do not see a physician, many physicians do not order a culture, and not every culture attempt yields salmonella. FoodNet has made it possible to directly measure the degree of under-reporting. For example, using the surveys of the population in general, and of clinical laboratories to estimate the likelihood that a person with diarrheal illness seeks medical care and gets cultured, we have estimated that for every person with acute salmonellosis diagnosed, there are another 37 symptomatic infections that went undiagnosed (CDC unpublished data). This means that the 33,608 culture-confirmed cases of salmonellosis reported in 1998 (CDC, 2000) were the tip of a much larger iceberg of illnesses that are estimated actually to have occurred in the United States, some 1.3 million in all.

National objectives for the control of specific foodborne diseases were developed in the late 1980s for the year 2000 (US Department of Health & Human Services, 1991). These objectives were set based on modest declines from the 1987 baseline. FoodNet data indicate that we have made substantial progress. Encouragingly, it appears that the United States has met or exceeded those goals relating to specific illness incidence (Table 1). Year to year variation may be substantial, but declines in the incidence of infections caused by several foodborne zoonotic pathogens may be early returns on the effort to improve foodborne disease prevention through HACCP in the meat industry, better egg safety measures, and food safety education. Now, national goals have been drafted for 2010 that are even more ambitious, representing a 50% reduction from the baselines of 1997 (US Department of Health & Human Services, 1998). Reliable surveillance data provided by FoodNet will be critical to tracking progress towards these goals.

A second improvement in surveillance is the National Antimicrobial Resistance Monitoring System for Enteric Bacteria, or NARMS-EB. This system collects a representative sample of isolates of major foodborne pathogens and tests them for resistance to a standard battery of antimicrobial agents. Since 1996, this has provided early warning for the appearance of strains of *Salmonella* that are resistant to drugs that are critical treatment choices, such as fluoroquinolone, and ceftriaxone (Dunne et al., 2000; Herikstad et al., 1997). NARMS identified a major nationwide increase in resistance to fluoroquinolones in *Campylobacter*, which in a FoodNet case-control study was associated with consumption of poultry and with travel to other countries (Kassenborg et al., 2000). Because the appearance of resistance in these organisms is related to the use of these or similar antimicrobial agents in their animal reservoirs, these findings have implications for veterinary as well as human medicine, and they were instrumental in propelling the recent proposed withdrawal in approval of fluoroquinolones for poultry.

## 2. Foodborne outbreaks

A common-source outbreak is recognized when a group of people develop the same disease after the same exposure, so that the number of cases of the disease is greater than would be expected. Investigation by public health authorities can identify a specific route of transmission, such as air, or water, or food, and for foodborne outbreaks, the specific food vehicle, such as ground beef or alfalfa sprouts. These outbreak investigations are conducted to identify the source and control it, so that further cases are immediately prevented. They are also conducted to improve our ability to prevent future similar outbreaks. Typically, it is during outbreak investigations that new pathogens are first identified. Outbreaks are often the occasion to learn something new about an established pathogen, such as its appearance in a new food vehicle, or transmission via a new or unexpected route. Outbreak investigations are a fundamental part of public safety, preventing illness and death, and reassuring the public. If we can learn how to prevent future similar events, the victims will not have suffered in vain. Well-conducted investigations also minimize the economic damage that outbreaks cause, both by halting new cases and by improving the precision of control measures.

## 3. The “new scenario” outbreak

The textbook scenario for a foodborne outbreak is usually presented as an obvious event that is easy to detect, investigate and control. When 50% of the guests at a wedding party are violently ill the following day, it does not take a sophisticated surveillance system to detect the problem, nor a great deal of effort to identify which item on the menu was statistically more likely to have been eaten by the ill guests than by the ones who remained well. A specific and egregious error at a local kitchen may be the source of the problem, that allowed bacteria to grow in the contaminated food to counts high enough to make most ill who ate that food. Such outbreaks do in fact occur in the real world, and are a regular feature of the public health landscape. However, outbreaks are being recognized more frequently that follow a quite different scenario. These "new scenario" outbreaks are dispersed and widespread. They affect only a small proportion of those who are exposed, and are the result of low-level or intermittent contamination of a foodstuff that is distributed to many locations at once. These outbreaks are difficult to detect locally, because they cause only a modest increase in the number of apparently "sporadic" cases in any one location. Nonetheless, they can be quite large. An outbreak that caused 10 extra cases of salmonellosis in each of 20 states would be 200 additional diagnosed infections overall, which using the above multiplier, would represent 76,000 actual illnesses.

Such outbreaks are best detected by spotting an increase in a particular subtype of the organism. For example, they may be detected because of an increase in a particular serotype of *Salmonella*, or by an increase in strains with a particular molecular fingerprint. This means that a national surveillance network that examines the characteristics of the foodborne pathogens is critical to detecting and investigating such outbreaks. Once the outbreak is detected, a complex collaborative investigation involving multiple jurisdictions may be needed to identify a particular food vehicle. When it can be traced back to the likely point of contamination, it is often found to be the result of an industrial contamination event, far back in the chain of production. This event may have led to the low level contamination of a considerable quantity of food, which may need to be recalled. Identifying, understanding and correcting such events is central to the general process of making the food supply safer for all. Open discussion of the nature of the problem is important, as the implications are often industry wide.

The capacity of public health surveillance in the United States to detect and investigate such widespread outbreaks has been improving dramatically in recent years, because of a network called PulseNet (Swaminathan, Barrett, Hunter, & Tauxe, 2001). PulseNet, the national network for molecular subtyping of foodborne bacterial pathogens, is being implemented in state and large city public health laboratories, as well as in regulatory agencies. The program was piloted in the first states in 1996. By the end of the year 2000, 46 states were participating. These participating laboratories are equipped and trained to use a standardized procedure called pulsed field gel electrophoresis, or PFGE on the DNA of the bacteria isolated from ill persons. Because this information is not immediately relevant to the care of a the individual patient, it is not done by the clinical laboratory. We depend on those laboratories to send the pathogens that they isolate to the nearest public health laboratory for testing. PFGE is a method of molecular "fingerprinting" that gives a high level of bacterial strain discrimination, and that yields epidemiologically meaningful results. The public health laboratories that participate can perform PFGE on a variety of different bacterial pathogens, including *E. coli* O157:H7, *Salmonella*, *Campylobacter*, *Shigella*, and *Listeria*, and even non-foodborne pathogens such as meningococcus (Popovic et al., 2001). The results from the different laboratories can be compared online with each other and with a national database maintained at CDC. As an Internet-based network, this permits rapid comparison with the results of PFGE typing across many states, so that the appearance of a new pattern or an increase in a pattern occurring in many states at once will be detected. When an increase or cluster is flagged, a detailed epidemiologic investigation can often determine the source; it is the powerful combination of microbiological and epidemiologic methods that makes these successful investigations possible.

A second enhancement in the capacity to detect dispersed outbreaks has been a new statistical tool, called Surveillance Outbreak Detection Algorithm, or SODA (Hutwagner, Maloney, Bean, Slutsker, & Martin, 1997). This algorithm was developed to analyze routine national *Salmonella* serotyping information in order to identify increases in reported cases above an expected baseline, at the state, regional and national levels, for each of the 500 or so serotypes reported in the United States. This algorithm is run regularly at CDC on serotype data submitted by the State public health laboratories. It flags clusters, which can then be targeted for PFGE analysis and epidemiologic investigation. The same algorithm is being implemented now for *Shigella* and *E. coli* O157:H7.

In recent years, new scenario outbreaks have been dramatic, and their investigations have led to important advances. In 1997, shortly after the state health department of Colorado began testing their *E. coli* O157:H7 isolates in PulseNet, 16 cases of infection with the same unusual pattern were detected in Colorado and a neighboring state (CDC, 1997). These cases were linked to ground beef produced at a large factory. Because the leftover ground beef from one production lot was routinely worked into subsequent days' production, the ultimate recall was enormous, 25 million pounds. In 1998, an increase in "sporadic" *Listeria* cases occurred in several states, just as the PulseNet method for *Listeria* was ready for pilot implementation. Ultimately 101 cases with the same pattern were identified in 22 states and were associated with eating cooked hot dogs from one production plant (CDC, 1999). The company itself instituted a recall of the hot dog products. Investigation at that plant suggested that further measures were needed to control recontamination of hot dogs after processing. Such measures are being considered by the entire industry. In 1999, A cluster of *Salmonella* Newport infections was detected by SODA and PFGE subtyping within the serotype (Sivapalasingam et al., 2000). Ultimately 78 infections with the same PFGE profile in 13 states were identified. Epidemiologic investigation linked these cases to consumption of fresh imported mangoes. The mangoes had been treated with a new hot water dip process to eliminate fruit fly infestation before export, a process that may have also introduced *Salmonella* into the mangoes. As a result, the process is being modified, as it is introduced worldwide to replace ethylene chloride treatments. In 2000, an SODA cluster of *Salmonella* Enteritidis infections with the same unusual PFGE pattern was detected in western states; 88 infections in eight states were ultimately associated with drinking unpasteurized orange juice that had been treated with an alternative to pasteurization (Rangel et al., 2000). Following this outbreak, the federal regulations for juice were revised to make contamination less likely to recur (FDA, 2001).

It is likely that dozens of "new scenario" outbreaks occur each year in the United States. In fact in fiscal year 1999, we participated in the investigation of 12 foodborne outbreaks that each affected persons in three or more states simultaneously. Such outbreaks may represent an important fraction of what now appear to be many isolated sporadic cases. As surveillance improves, and more outbreaks are detected, it would be reasonable to expect the number of such outbreaks to appear to increase. This does not mean that the food supply is becoming less safe. In fact, as public health authorities, regulators and industry identify and correct the problems that lead to them, one should expect the food supply to actually become safer.

## 4. Final thoughts

The last decade has witnessed several encouraging trends in the thinking about food safety. First, it has become clear that the responsibility for food safety is distributed along the entire food chain of production, and does not reside solely with the final consumer. Second, new strategies have been adopted that engineer safety into food products, such as HACCP and good agricultural practices. There is a growing recognition that the problems identified in the course of outbreak investigations are of concern to the entire food industry and thus merit open and public discussion; they serve as an impetus to make the entire industry safer. Increasingly, good epidemiologic data are being used to guide action that protects the public health. Finally, new surveillance tools are increasing the detection of widespread multi-jurisdictional foodborne outbreaks that may be more common than previously recognized.

Foodborne diseases remain an important challenge to public health in the United States and many other countries, causing a major burden of illness and requiring substantial resources for their control and prevention. New active surveillance strategies can provide better data on the burden of illness and can track trends in the incidence of specific diseases as prevention improvements such as HACCP are implemented. New surveillance tools such as reproducible molecular fingerprinting of pathogens are increasing our capacity to detect widespread and dispersed outbreaks. Investigation of such outbreaks can yield important insights in how to improve prevention strategies. Many foodborne diseases are preventable, though prevention will require a number of control efforts along the chain from production to consumption. While important progress has been made to date, as a result of recent improvements in food safety, further prevention efforts are required in the United States if we are to reach the public health objectives set for 2010.

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