Activities, Achievements, and Lessons Learned during the First 10 Years of the Foodborne Diseases Active Surveillance Network: 1996–2005

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Since the establishment of the Foodborne Diseases Active Surveillance Network (FoodNet) in 1996, it has been an essential resource for the surveillance and investigation of foodborne disease in the United States. FoodNet has had a major impact on food safety because it conducts population-based, active surveillance for laboratory-confirmed infections from 9 pathogens commonly transmitted through food. Each year, FoodNet publishes the National Report Card on Food Safety, which is used by regulatory agencies, industry and consumer groups, and public health personnel to prioritize and evaluate food safety interventions and monitor progress toward national health objectives. FoodNet also determines the human-health impact of foodborne illness by conducting related epidemiological studies that contribute to the estimates of the overall burden of foodborne illness, attribute the burden of foodborne illness to specific foods and settings, and address important foodborne disease-related issues, such as antimicrobial resistance and sequelae from foodborne infections. This article summarizes the activities, achievements, and lessons learned during the first 10 years of FoodNet.

Foodborne infections are an important public health problem that caused an estimated 76 million illnesses in the United States in 1999 [1]. Although advances in technology, regulation, and education have dramatically improved the safety of the food supply, the mass production, distribution, and importation of food has brought new challenges. Moreover, new and emerging foodborne pathogens and novel food vehicles continue to be described. Surveillance to determine the human health burden of disease and to measure improvements of food safety, therefore, continues to be a challenging, but critical, public health priority. In the United States, the Foodborne Diseases Active Surveillance Network (FoodNet) has been producing more precise and accurate estimates of the burden and sources of specific foodborne diseases since its establishment in 1996 [2, 3]. This article summarizes the activities, achievements, and lessons learned during the first 10 years of FoodNet.

FOODNET ORGANIZATION

FoodNet is the principal foodborne disease component of the Centers for Disease Control and Prevention’s (CDC) Emerging Infections Program and is a collaborative project among the CDC, the US Department of Agriculture’s Food Safety and Inspection Service, the US Food and Drug Administration, and the state health departments of Emerging Infections Program sites.

When FoodNet was established in 1996, there were 5 FoodNet sites (California, Connecticut, Georgia, Minnesota, and Oregon). Since then, the number of sites has doubled, with the addition of New York and Maryland in 1998, Tennessee in 2000, Colorado in 2001, and New Mexico in 2004 (figure 1). The population that is surveilled by FoodNet is large and accounted for 15% of the US population (44.9 million persons) in 2005. Although the population that is surveilled by FoodNet was not chosen to be representative of the United States, a demographic comparison of the 2005 FoodNet and US census populations suggests that differences are limited; the only no-
Table difference is the underrepresentation of the Hispanic population at FoodNet sites (9% vs. 14%).

**FOODNET OBJECTIVES**

The key objectives of FoodNet are to determine the burden of foodborne disease, monitor trends of the burden of specific foodborne diseases over time, attribute the burden of foodborne illness to specific foods and settings, and develop and assess interventions to reduce the burden of foodborne illness. To meet these objectives, FoodNet conducts active surveillance and epidemiologic studies [2, 3].

**DETERMINING THE BURDEN OF FOODBORNE DISEASE**

FoodNet has had a major impact on food safety in the United States because it conducts population-based, active surveillance for laboratory-confirmed infections from pathogens commonly transmitted through food. Surveillance for *Campylobacter* species, *Listeria monocytogenes*, *Salmonella* species, *Shigella* species, Shiga toxin–producing *Escherichia coli* O157, *Vibrio* species, and *Yersinia enterocolitica* has been conducted since 1996. Surveillance for *Cryptosporidium* and *Cyclospora* species began in 1997, and surveillance for non-O157 Shiga toxin–producing *E. coli* began in 2000. Although some laboratory-confirmed infections are passively reported to the CDC, there were no reliable data on the burden of *Campylobacter*, *E. coli* O157, *L. monocytogenes*, *Vibrio*, or *Y. enterocolitica* infections before the establishment of FoodNet.

In contrast to “passive” laboratory-based surveillance systems, which rely upon reports of foodborne diseases from clinical laboratories to state and local health departments and then to the CDC, FoodNet personnel actively contact clinical laboratories (either weekly or monthly, depending on the size of the laboratory) to ascertain laboratory-confirmed cases occurring within the surveillance area. Clinical laboratories are identified using state licensing lists and physician surveys [4]. All clinical laboratories serving the FoodNet population are contacted, including larger reference laboratories that receive specimens from—but are geographically located outside—the 10 FoodNet sites. Each clinical laboratory is audited at least twice yearly to ensure that all cases of disease under surveillance are ascertained and that changes in incidence are not a result of surveillance artifacts. In 2006, there were >600 clinical laboratories serving the FoodNet sites. Those located outside FoodNet sites contribute approximately one-fifth of the cases. Frequent audits demonstrate >95% ascertainment during prospective active surveillance.

Several surveillance steps are necessary for a case to be ascertained by laboratory-based surveillance: the ill person must seek medical care, a stool specimen must be submitted, and the laboratory must test for the pathogen and report the case to a public health agency (figure 2). Therefore, although active surveillance and routine audits ensure that all laboratory-confirmed cases occurring in the FoodNet surveillance area are ascertained, cases may not be ascertained because a person seeks medical care and diagnostic practices are performed.

Before the inception of FoodNet, there were no precise estimates of the overall human health burden of foodborne illness in the United States. Policy-makers and regulatory agencies, when faced with allocating limited resources, had difficulty as-
Figure 2. Surveillance steps that must occur for a laboratory-confirmed case to be ascertained through active surveillance.

sessing the burden of foodborne illness. FoodNet advanced the science of this aspect by adopting a paradigm known as the “burden-of-illness pyramid.” By estimating the frequency of cases of foodborne disease that go undetected at each surveillance step (seeking of medical care, stool specimen submission, and laboratory testing), FoodNet can account for surveillance gaps and, therefore, allow an extrapolation from laboratory-confirmed cases (top of the burden-of-illness pyramid) to estimate the overall burden of disease in the community (bottom of the burden-of-illness pyramid).

FoodNet estimates the frequency of cases of foodborne disease that go undetected because of laboratory testing practices by conducting surveys of clinical diagnostic laboratories that serve the FoodNet population [5, 6]. Repeated cycles of the FoodNet Laboratory Survey also allow FoodNet to detect temporal or geographical differences of clinical laboratory practices that may contribute to variations of pathogen isolation rates. For example, the percentage of stool samples cultured for *E. coli* O157 in laboratories that cultured all bloody stool samples for *E. coli* O157 varied markedly by site (from 58% in Georgia to 96% in Connecticut) [7].

The frequency at which persons with an acute diarrheal illness seek medical care and submit a stool culture has been estimated by cross-sectional telephone surveys of the general population [8–10]. The FoodNet Population Survey also provides an estimate of the prevalence of acute diarrheal illness, and repeated cycles of the survey help validate that changes of disease incidence are not because of changes of care seeking or specimen submission [11, 12]. This platform has also been used to collect baseline information of the consumption of “risky” foods; these data have been useful for hypotheses generation during outbreak investigations [13]. The attitudes and practices of a range of foodborne illness-related topics, including antibiotics [14], food irradiation [15], food-handling [16], and sources of gastroenteritis [17], have also been described.

Originally, FoodNet considered that physician surveys might provide information about the frequency of stool sample submissions [4]. However, several biases were considered to have lead to an overestimation of stool sample submission rates as a result of this method, and patient reports from the FoodNet Population Survey have been used instead. FoodNet Physician Surveys have, however, been useful for the description of physician practices and determination of the current role of physicians as food-safety educators [4, 18].

By augmenting surveillance with information from FoodNet Laboratory Surveys [5, 6] and the FoodNet Population Survey [8, 9], FoodNet has been able to estimate the overall burden of illness due to specific pathogens. For example, FoodNet estimates that, during 2004, for each laboratory-confirmed case of *Salmonella* infection, there were 38 cases in the community [19]. Data from FoodNet surveillance and related epidemiological studies were vital to the CDC’s estimate of foodborne illness in the United States [1], and these data have contributed to estimates of the economic cost of foodborne illness [20, 21].

For determination of the overall burden of foodborne illness, FoodNet also considers the impact of complications from foodborne infections. FoodNet began surveillance for hemolytic uremic syndrome, a serious complication of *E. coli* O157 infection, in persons aged <18 years during 1997, using prospective reporting by pediatric nephrologists. Three FoodNet sites have pilot-tested the use of hospital discharge data to determine the burden of Guillain-Barré syndrome, an important sequelae of *Campylobacter* infection. In addition to these syndromes, 2 sites have examined the impact of reactive arthritis following a laboratory-confirmed bacterial infection, and 1 site conducted a survey to determine the frequency of self-reported complications from enteric infections [23].

**MONITOR TRENDS OF THE BURDEN OF SPECIFIC FOODBORNE DISEASES**

The expansion of the FoodNet sites presented a challenge with regard to monitoring the change of incidence over time, because site-to-site variation of the incidence of laboratory-confirmed infection can cause the collective crude incidence to change, even if no actual change of incidence actually occurred. FoodNet reports of the description of trends of the incidence of laboratory-confirmed infections over time from before 2001 limited their assessment to the 5 original sites [7, 24–27]. In 2001, FoodNet overcame this limitation by adopting the use of a negative binomial model to account for variations intro-
The knowledge of which foods cause the most human illness is essential for the development and prioritization of food safety interventions. In the United States, the approach to attribution has been multifaceted, involving a variety of public health, regulatory, and academic organizations [30]. FoodNet has been able to make a unique contribution to attribution by using its surveillance platform to conduct studies to determine the risk factors for sporadic infections [31–43].

FoodNet case-control studies have highlighted known risk factors for specific foodborne infections, including ground beef and E. coli O157 infection [37] and chicken and Campylobacter infection [31]. FoodNet studies have also identified food vehicles previously unrecognized as risk factors in the United States, including chicken as a risk factor for Salmonella enterica infection [33, 40] and hummus and melon as risk factors for Listeria monocytogenes infection [41]. A recent study identified riding in a shopping cart next to raw meat or poultry as a novel risk factor for Salmonella and Campylobacter infection in infants [42, 43].

In 2006, FoodNet will launch a case-control study involving

Table 1. Incidence of bacterial and parasitic infection and postdiarrheal hemolytic uremic syndrome that were surveilled by the Foodborne Diseases Active Surveillance Network (FoodNet; United States, 2005), by site, compared with national health objectives for 2010.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>CA</th>
<th>CO</th>
<th>CT</th>
<th>GA</th>
<th>MD</th>
<th>MN</th>
<th>NM</th>
<th>NY</th>
<th>OR</th>
<th>TN</th>
<th>Overall for 2005</th>
<th>National health objectivea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campylobacter species</td>
<td>27.96</td>
<td>19.37</td>
<td>15.47</td>
<td>6.52</td>
<td>7.23</td>
<td>16.51</td>
<td>18.28</td>
<td>11.70</td>
<td>17.69</td>
<td>6.98</td>
<td>12.72</td>
<td>12.30</td>
</tr>
<tr>
<td>Listeria species</td>
<td>0.31</td>
<td>0.08</td>
<td>0.57</td>
<td>0.28</td>
<td>0.34</td>
<td>0.29</td>
<td>0.21</td>
<td>0.42</td>
<td>0.31</td>
<td>0.19</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Shigella species</td>
<td>8.70</td>
<td>3.95</td>
<td>1.66</td>
<td>7.48</td>
<td>1.78</td>
<td>1.90</td>
<td>6.94</td>
<td>1.53</td>
<td>2.26</td>
<td>4.89</td>
<td>4.67</td>
<td>NA</td>
</tr>
<tr>
<td>Shiga toxin–producing E. coli O157</td>
<td>0.87</td>
<td>1.02</td>
<td>1.23</td>
<td>0.39</td>
<td>0.47</td>
<td>2.35</td>
<td>0.53</td>
<td>1.71</td>
<td>1.84</td>
<td>0.78</td>
<td>1.06</td>
<td>1.00</td>
</tr>
<tr>
<td>Non–O157 Shiga toxin–producing E. coli</td>
<td>0.16</td>
<td>0.12</td>
<td>0.57</td>
<td>0.09</td>
<td>0.68</td>
<td>0.80</td>
<td>0.53</td>
<td>0.25</td>
<td>0.22</td>
<td>0.03</td>
<td>0.33</td>
<td>NA</td>
</tr>
<tr>
<td>Vibrio species</td>
<td>0.69</td>
<td>0.31</td>
<td>0.34</td>
<td>0.24</td>
<td>0.49</td>
<td>0.12</td>
<td>0.05</td>
<td>0.19</td>
<td>0.25</td>
<td>0.08</td>
<td>0.27</td>
<td>NA</td>
</tr>
<tr>
<td>Yersinia species</td>
<td>0.87</td>
<td>0.27</td>
<td>0.43</td>
<td>0.29</td>
<td>0.13</td>
<td>0.35</td>
<td>0.11</td>
<td>0.51</td>
<td>0.45</td>
<td>0.31</td>
<td>0.36</td>
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</tr>
<tr>
<td>Parasites</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptosporidium species</td>
<td>1.43</td>
<td>0.94</td>
<td>2.34</td>
<td>1.64</td>
<td>0.61</td>
<td>3.22</td>
<td>1.05</td>
<td>16.38</td>
<td>1.34</td>
<td>0.73</td>
<td>2.95</td>
<td>NA</td>
</tr>
<tr>
<td>Cyclospora species</td>
<td>0.06</td>
<td>0.00</td>
<td>1.00</td>
<td>0.15</td>
<td>0.05</td>
<td>0.00</td>
<td>0.21</td>
<td>0.02</td>
<td>0.11</td>
<td>0.05</td>
<td>0.15</td>
<td>NA</td>
</tr>
<tr>
<td>Hemolytic uremic syndrome</td>
<td>0.94</td>
<td>1.02</td>
<td>0.47</td>
<td>0.44</td>
<td>0.80</td>
<td>1.51</td>
<td>0.00</td>
<td>0.83</td>
<td>1.33</td>
<td>2.34</td>
<td>1.0c</td>
<td>0.9</td>
</tr>
<tr>
<td>Population in surveillance, millions</td>
<td>3.21</td>
<td>2.56</td>
<td>3.50</td>
<td>8.83</td>
<td>5.66</td>
<td>5.10</td>
<td>1.90</td>
<td>3.59</td>
<td>5.90</td>
<td>44.47</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

NOTE. Data are incidence of infection per 100,000 persons, unless otherwise indicated. CA, California; CO, Colorado; CT, Connecticut; GA, Georgia; MD, Maryland; MN, Minnesota; NM, New Mexico; NY, New York; OR, Oregon; TN, Tennessee.

a Objectives are for incidence of Campylobacter, Salmonella, and Shiga-toxin–producing E. coli O157 infections for 2010 and for incidence of Listeria infection for 2005.

b Not applicable because there is no national health objective.

c 2004 data reported for hemolytic uremic syndrome incidence. Incidence rate of postdiarrheal hemolytic uremic syndrome in children <5 years old; rate calculation based on population <5 years old in surveillance.

2 emerging Salmonella serotypes with limited information for attribution, S. serotype Javiana and S. serotype I 4,[5],12:i:-. This study will include validation substudies aimed at better understanding of the impact of selection and misclassification bias. To additionally advance the methodology that is employed for sporadic case-control studies of enteric infections, FoodNet is collaborating with the European Med-Vet-Net for a study to assess the impact of population immunity and writing an international review of methods with other members of the International Collaboration on Enteric Disease Burden of Illness Studies.

Data from FoodNet surveillance contributes to attribution in other ways. Since 2004, FoodNet has collected information on international travel history from patients with Salmonella and E. coli O157 infections, which allows an estimate of the burden of domestically acquired illness. FoodNet can also enhance surveillance to collect additional exposure information. For example, during 2005, all patients with laboratory-confirmed Shigella infection were interviewed about risk factors that may have been prevalent during the week before illness onset. Although a comparison group was not interviewed, this provided useful information on the proportion of patients with risk factors for shigellosis, and the proportion of patients who did not report any of the typical nonfood exposures provided a conservative estimate of the foodborne transmission.

FoodNet has also been working with the National Antimicrobial Resistance Monitoring System and the Food and Drug Administration to conduct a Retail Food Study to monitor the prevalence and antimicrobial resistance of Campylobacter and Salmonella organisms that are isolated from random sampled meat and poultry products from grocery stores at FoodNet sites [44]. A FoodNet Grocery Store Survey was launched at 2 FoodNet sites during 2006 to quantify Campylobacter levels in retail chicken products and to test the hypothesis that regional differences result from differences in Campylobacter dose on retail poultry products.

OTHER FOODNET CONTRIBUTIONS

FoodNet’s greatest asset is the network of public health professionals that it brings together to work on foodborne issues of national importance. This infrastructure has allowed FoodNet sites to initiate rapid surveillance for new and emerging foodborne pathogens that are not currently under surveillance. During past years, FoodNet has conducted surveillance for variant Creutzfeldt-Jakob disease and Enterobacter sakazakii [3]. More recently, FoodNet has implemented surveillance for community-acquired Clostridium difficile because of nationwide discussions about the changing epidemiology of this pathogen.

Other surveillance systems managed by the CDC collect information about enteric pathogens; therefore, epidemiological and laboratory data from 1 person may be contained in >1 system. Linking data between systems increases the utility of surveillance data, and FoodNet is working with others to achieve this goal. For example, retrospective linking of FoodNet and National Antimicrobial Resistance Monitoring System data
demonstrated the human health impact of antimicrobial-resistant infections result [47–49], which was used to support the Food and Drug Administration ban on use of fluoroquinolones during poultry production [49]. When case-control study data are available, linked data allows for the identification of risk factors associated with specific resistance patterns, phage types, or molecular subtypes. For example, prior antimicrobial agent use has been associated with an increased risk of multidrug-resistant S. enterica serotype Typhimurium infection [35], international travel has been associated with an increased risk of fluoroquinolone-resistant Campylobacter infection [37], and Newport–multidrug-resistant AmpC infections have been shown to be acquired through the US food supply—most likely from bovine and, perhaps, poultry sources—and particularly among persons already taking antimicrobial agents [50]. A recent case-control study was able to discriminate between chicken and eggs as risk factors for S. Enteritidis infection with PT8 and 13, respectively [40].

FoodNet sites serve as a model for improving surveillance nationwide. For example, FoodNet sites pilot-tested an enhanced surveillance scheme for listeriosis, which was subsequently rolled out nationwide during 2005. FoodNet has also been working with the CDC’s Outbreak Network for Foodborne Disease Surveillance and Response and the Environmental Health Specialists Network to better characterize the factors associated with determining an etiology and to report contributing factors (e.g., cross-contamination) by collecting supplemental information about outbreaks of infection that occur at FoodNet sites [45]. In an effort to improve stool culturing rates and etiology determination, 1 FoodNet site pilot-tested a program for the delivery stool kits during outbreak investigations [46].

FoodNet has also had an impact on the surveillance of foodborne disease internationally. FoodNet’s approach to estimating the impact of foodborne disease using the burden of illness pyramid has been adopted in other countries, and FoodNet is part of an international working group, the International Collaboration on Enteric Disease Burden of Illness Studies, which aims to further improve the methods used to estimate the burden of foodborne illness [10, 22]. FoodNet is also an active member of the World Health Organization Global Salm-Surv (http://www.who.int/salmsurv/en/), which is a global network of laboratories and public health professionals working to strengthen laboratory-based surveillance of foodborne diseases worldwide.

DEVOLVE AND ASSESS INTERVENTIONS TO REDUCE THE BURDEN OF FOODBORNE ILLNESS

FoodNet is an important resource that provides vital information to aid national decision-making when allocating resources and directs prevention strategies aimed at improving the safety of the food supply. By describing trends in laboratory-confirmed infections, FoodNet has been able to describe the burden of foodborne illness, identify populations at risk, and provide the data for prioritizing and evaluating the success of interventions. Related epidemiological studies have supported the development and assessment of interventions by improving our understanding of the risk factors for infection, generating new ideas on how foodborne illnesses are transmitted, and better defining the overall burden and human-health impact.

FoodNet highlights important public health messages and works closely with regulatory and other partners to ensure that the information gained through this network is used to inform food safety policy. FoodNet trends and findings from FoodNet studies are widely disseminated using a variety of mechanisms, including annual summaries (Morbidity and Mortality Weekly Report and annual reports), journal and newsletter publications, oral and poster presentations at national and international meetings, presentations to industry and consumer groups, and the FoodNet Web site (http://www.cdc.gov/FoodNet).

FUTURE DIRECTION

Since 1996, FoodNet has enhanced the surveillance and investigation of foodborne infection. FoodNet is an excellent example of partnership between federal and states agencies has contributed to the improvement of food safety in the United States in numerous ways. As FoodNet moves into its second decade, it will continue to publish annually the National Report Card on Food Safety, as well as strive to improve the examination of temporal, geographical, and demographical trends. Growing interest in the burden of foodborne disease studies internationally has presented an exciting opportunity for FoodNet to expand its science base and contribute to the global estimate of the burden of foodborne disease.

FoodNet will continue to use its infrastructure to respond to newly emerging public health threats and to address important foodborne disease–related issues. Antimicrobial resistance and sequelae from foodborne infections remain important subjects of focus. During 2006, a joint FoodNet–National Antimicrobial Resistance Monitoring System cohort study was launched to prospectively compare clinical outcomes from multidrug-resistant and pan-susceptible Salmonella infections. A FoodNet cohort study of persons with laboratory-confirmed E. coli O157 infection was launched during 2006 to determine the effect of antibiotics on the development of hemolytic uremic syndrome. This study aims to inform patient treatment practices and provide the data needed to form a consensus with regard to the relative importance of this putative risk factor.

A maturation of FoodNet methods for determining and monitoring disease burden has allowed a shift in focus from the first 2 FoodNet objectives to the third objective, which is
the attribution of the burden of foodborne disease to specific foods and contexts. Although FoodNet case-control studies have contributed—and will continue to contribute—to the attribution, FoodNet is working on a variety of other approaches that will also help meet this objective. The attribution of cases of foodborne disease to specific food vehicles and other sources will be an invaluable tool for policymakers who are developing strategies aimed at reducing the impact of foodborne disease.

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