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Review

Approaches to the Surveillance of Foodborne Disease: A Review of the Evidence

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Abstract

Foodborne disease surveillance aims to reduce the burden of illness due to contaminated food. There are several different types of surveillance systems, including event-based surveillance, indicator-based surveillance, and integrated food chain surveillance. These approaches are not mutually exclusive, have overlapping data sources, require distinct capacities and resources, and can be considered a hierarchy, with each level being more complex and resulting in a greater ability to detect and control foodborne disease. Event-based surveillance is generally the least resource-intensive system and makes use of informal data sources. Indicator-based surveillance is seen as traditional notifiable disease surveillance and consists of routinely collected data. Integrated food chain surveillance is viewed as the optimal practice for conducting continuous risk analysis for foodborne diseases, but also requires significant ongoing resources and greater multisectoral collaboration compared to the other systems. Each country must determine the most appropriate structure for their surveillance system for foodborne diseases based on their available resources. This review explores the evidence on the principles, minimum capabilities, and minimum requirements of each type of surveillance and discusses examples from a range of countries. This review forms the evidence base for the *Strengthening the Surveillance and Response for Foodborne Diseases: A Practical Manual*.

Introduction

Many countries conduct surveillance for diseases from contaminated food, as they are a common cause of morbidity and mortality and result in substantial economic impact (Flint *et al.*, 2005; Buzby and Roberts, 2009; Hoffmann *et al.*, 2012). Foodborne diseases are defined as diseases that ''result from the ingestion of contaminated foods and food products and include a broad range of illnesses caused by parasites, chemicals and pathogens which contaminate food at different points in the food production and preparation process'' (WHO, 2008b). They are a subset of many enteric infections that can be transmitted through a number of different routes. Foodborne disease surveillance systems aim to reduce the burden of illness through monitoring disease trends; estimating burden; identifying and controlling outbreaks; identifying high-risk foods and poor food preparation practices; identifying vulnerable groups; determining foodborne transmission pathways for specific pathogens; assessing food safety programs; and providing information and evidence to help policymakers with prevention strategies (Borgdorff and Motarjemi, 1997).

There are several different approaches to foodborne disease surveillance, including event-based surveillance, indicator-based surveillance and integrated food-chain surveillance. Each approach has a different focus on foodborne disease. These types of surveillance are not mutually exclusive and overlap in the use of data sources. They have differing success at achieving the goals of surveillance and require distinct capacities and resources.

Due to limited resources and public health infrastructure, many low-income countries are unable to develop formal foodborne disease surveillance systems and rely primarily on syndromic surveillance (Chiller *et al.*, 2005; Dagina *et al.*, 2013). By increasing resources for laboratory capacity and infrastructure, some low- and middle-income countries have been able to develop laboratory-based surveillance for foodborne diseases (Chiller *et al.*, 2005; Deng *et al.*, 2012; Vinas *et al.*, 2013). Integrated food-chain surveillance, which uses data from each point across the food chain, is the most complex system, with examples in several European countries (Ammon and Makela, 2010; David *et al.*, 2011; DANMAP, 2013). While there is a hierarchy for strengthening surveillance systems themselves, ''there is no clear 'best-method' used in any of these surveillance systems—each system has evolved in accordance

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with the needs and resources of the geographical area involved'' (WHO, 2001). Countries face many challenges in finding the best method for foodborne disease surveillance, with an ultimate aim of improving systems and maintaining sustainability, while balancing fluctuating national and international political, budgetary, and disease priorities. In particular, it is important that any new system for foodborne diseases fits with other surveillance initiatives in order to avoid the development of vertical programs for surveillance and control (Chiller *et al.*, 2005).

The World Health Organization (WHO) commissioned this review for an informal consultation meeting in February 2014, which aimed to produce a guidance document that could be used by countries: *Strengthening Surveillance and Response for Foodborne Diseases: A Practical Manual*. In this review, we review the principles, minimum capacities, and basic requirements for different types of foodborne disease surveillance using examples from different countries.

Methods

We reviewed the literature on event-based surveillance, indicator-based surveillance, and integrated food-chain surveillance.

Definitions

Event-based surveillance (EBS) is characterized by the rapid identification of information about events that are a potential risk to public health. Unlike traditional surveillance systems, there is no systematic collection of routine data and disease/syndrome definitions are not used. The sources of information include rumors and disease reports transmitted through formal and informal channels (WHO Western Pacific Region, 2008).

Indicator-based surveillance (IBS) is regarded as traditional surveillance and includes datasets of notifiable disease surveillance, syndromic surveillance, sentinel surveillance, hospital diagnosis and death registers, laboratory-based surveillance, and antimicrobial resistance surveillance (Box 1) (WHO, 2011). IBS is defined as ''the systematic collection and analysis of timely, reliable and appropriate data on priority diseases, syndromes and conditions'' for public health action (WHO, 2011).

Integrated food-chain surveillance is seen as international best practice in the surveillance of foodborne disease (Galanis *et al.*, 2012). It involves integrating and streamlining a combination of passive and active collection, analysis, and interpretation of data from surveillance in the human, veterinary, and food sectors (WHO, 2014b; WHO Regional Office for Africa, 2012), and includes antimicrobial resistance monitoring.

Literature search and screening

We conducted a rapid review of the literature in February 2014 to provide an overview of approaches to the surveillance of foodborne diseases. We searched for research that examined different foodborne disease surveillance systems. Peer-review publications were identified using the bibliographic database and citation index Medline. Search terms included 'foodborne disease,' 'foodborne illness,' 'surveillance,' 'indicator,' 'sentinel,' 'syndromic,' 'event,' 'laboratory,' 'antimicrobial,' 'integrated,' and 'evaluation'. An additional search using Medical Subject Headings (MeSH) terms 'foodborne diseases,' 'public health surveillance,' 'sentinel surveillance,' 'population surveillance' and 'epidemiological monitoring' was conducted in Medline. Gray literature and national and international surveillance guidelines were found through scanning relevant government and international websites. The search terms used in Medline were also entered into Google, Google Scholar, and the WHO website.

Our search strategy focused on rapidly identifying high-quality peer-reviewed research, as well as national and international guidelines and documents. Studies were excluded if they were not published in English, provided duplicate evidence, or were not related to foodborne disease surveillance. Focus was placed on more recent papers, if available. One author (LF) searched, screened, and coded the studies for inclusion into this review.

Findings

Our search identified 686 papers or documents, 68 of which are included in this review. Findings are summarized below and in Table 1 by event-based, indicator-based, and integrated food-chain surveillance.

BOX 1. DEFINITIONS

Antimicrobial resistance surveillance: Testing and evaluation of foodborne disease pathogens for antimicrobial resistant trends (WHO, 2013).

Disease notifications: Notification or reporting by a physician or other health worker of a specific disease to a district, regional, or national public health authority. It requires routine reporting by health workers, data collection, data analysis, and reporting in surveillance bulletins (Borgdorff and Motarjemi, 1997).

Hospital diagnosis and death registration: Surveillance using data from hospital diagnoses and registration of causes of death with infectious gastroenteritis or pathogens known to cause foodborne disease.

Laboratory-based surveillance: Clinical and public health laboratories receive and test specimens obtained from patients with suspected foodborne disease: most commonly fecal samples from patients with diarrhea (Bordorff and Motarjemi, 1997; WHO, 2008a). Laboratories then report cases to public health authorities, and in some cases, isolates are sent to reference laboratories for typing or determination of antibiotic resistance patterns (WHO, 2008a).

Sentinel surveillance: A limited network of self-selected or purposely selected sites, from part of a target population as a representation of the larger population, to identify and notify about certain diseases or symptoms (CDC, 2014).

Syndromic surveillance: The use of health-related data based on clinical signs and symptoms rather than laboratory confirmation of diagnoses (WHO, 2014a).

EBS

Public health surveillance has been enhanced by the nontraditional approaches of EBS (Hartley *et al.*, 2010). Studies from the early 2000s note that almost all major outbreaks investigated by the WHO were first identified through informal sources, making EBS a critical source of epidemiological intelligence, particularly for the international spread of outbreaks (Grein *et al.*, 2000; Heymann and Rodier, 2004; Keller *et al.*, 2009). While there is a lack of techniques and methods for the evaluation of EBS (Hartley *et al.*, 2010) and few evaluations have been published, some successes of EBS systems in the timely and reliable identification of outbreaks have been documented in peer-reviewed articles for foodborne disease (Dagina *et al.*, 2013; Saupe *et al.*, 2013). An examination of the EBS system in Papua New Guinea by Dagina *et al.* (2013) reveals positive attributes as well as challenges and areas for improvement. EBS systems in Papua New Guinea were shown to be flexible, cost effective, and useful in quickly identifying diarrheal outbreaks that could be due to contaminated food (Dagina *et al.*, 2013); however, despite the ability to quickly capture data on outbreaks, a lack of resources at the response level and a lack of laboratory and epidemiological investigation capacity in low-income countries means that the source and etiology of outbreaks are unable to be determined for a large proportion of events (Dagina *et al.*, 2013). This in turn can hinder prevention efforts and food-safety policymaking.

An important characteristic of EBS noted in the literature is that it should be implemented in conjunction with an indicator-based surveillance system. The Integrated Disease Surveillance Project in India details some innovative approaches to EBS, such as media scanning and verification, community-based surveillance, and a call center, which are used as supplementary tools to the formal indicator-based system (Sharma *et al.*, 2009). These EBS strategies have been successful in identifying health events, including food poisoning; however, outbreak response and laboratory or epidemiological capacity is necessary to control the outbreak and identify specific sources and etiological agents causing foodborne disease.

New technologies and data sources, such as satellite imagery, radiofrequency identification, environmental sensors, and internet-based or social media disease detection, have expanded the activities of EBS and nontraditional surveillance (Brownstein *et al.*, 2009; Kamel Boulos *et al.*, 2010; Corley *et al.*, 2012; Hartley *et al.*, 2013). In areas with technological capabilities, health agencies using EBS have employed internet-based computer systems such as Argus, Biocaster, Global Public Health Intelligence Network, and EpiSPIDER to monitor informal sources on events affecting human health (Keller *et al.*, 2009; Hartley *et al.*, 2010). These systems can be effective but are insensitive. The majority are operating in North America and Europe (Agheneza, 2011) and face challenges such as topic detection and data acquisition from a high-volume stream of event reports and information dissemination to clients or to the public (Keller *et al.*, 2009). While these systems have the capability to quickly detect outbreaks potentially due to food, response capabilities and laboratory and epidemiological resources for investigation are needed to fully characterize a foodborne disease outbreak.

IBS

The main objectives of IBS systems for many countries are rapid detection of outbreaks, monitoring of disease trends over time, strengthening public health prevention and control programs, and informing public health policy (WHO Regional Office for the Western Pacific, 2010). IBS systems are operational in many countries, although there are a range of different structures, reporting methods, and timelines used. Although not foodborne disease specific, a meeting report of the best practices and ongoing challenges of IBS in the Western Pacific provides examples of IBS systems in China, Laos, and Malaysia, and highlights challenges such as the long list of diseases and syndromes under surveillance, duplicate or complicated case definitions, limited feedback from stakeholders, and lack of training (WHO Regional Office for the Western Pacific, 2010). As establishing new IBS systems is resource intensive, the focus is often on building on and strengthening existing systems in order to make them more useful and sustainable (WHO Regional Office for the Western Pacific, 2010; Mensah *et al.*, 2012).

A challenge common to IBS systems is the underreporting of foodborne disease, as many people with a foodborne disease either do not seek medical attention or, due to the nonspecific nature of the symptoms, will not be diagnosed (Borgdorff and Motarjemi, 1997; WHO, 2008a). An additional challenge of IBS systems is that there can be days or weeks between when a person is exposed and when a health department becomes aware of the illness, resulting in delayed identification of outbreaks (WHO, 2008a).

Notifiable disease surveillance

In countries with limited laboratory capacity, most diseases are syndromes only and do not rely on laboratory diagnosis, with notifications of clinical syndromes experienced by individuals. If a country has laboratory capacity, the notifications will often be of laboratory-confirmed illness in an individual. Notifications of foodborne disease can be used to identify outbreaks, describe epidemiological patterns, and monitor trends. Notifiable disease surveillance often detects severe cases of foodborne disease (for example, cases of botulism in Europe [Pingeon *et al.*, 2011], where notification is mandatory). Laboratory-confirmed disease notifications have been used to help estimate the burden of illness from foodborne disease (Scallan *et al.*, 2011). Public health staff can also detect foodborne disease outbreaks from increases in laboratory-confirmed notifications for diseases, such as salmonellosis (Denehy *et al.*, 2011), shigellosis (Guzman-Herrador *et al.*, 2013), and campylobacteriosis (CDC, 2013). Investigation capabilities are required to identify the food sources for these outbreaks.

Syndromic surveillance

Syndromic surveillance has been shown in a systematic review to be successful in low-resource settings, although implementation is not without its challenges (May *et al.*, 2011; WHO, 2014a). Syndromic surveillance often requires reporting of the aggregate number of cases occurring in a defined population and can be used to indicate the start of an outbreak of epidemic-prone diseases, such as collection of data on acute watery diarrhea as a proxy for cholera (May *et al.*, 2011).

Table 1. Components of Foodborne Disease Surveillance

	Minimum capabilities	*Minimum requirements*	*Advantages*	*Challenges*
Event-based surveillance (EBS) (WHO Western Pacific Region, 2008; Keller *et al.*, 2009; Dagina *et al.*, 2013)	• Timely detection of foodborne events	• An event assessment team/unit responsible for assessing each event and triggering a response • Rapid response capacity • All methods of immediate communication available to those expected to participate in EBS • Reporting 24 h a day, 7 days a week • Rapid data collection in a database that captures enough information to allow for initial assessment • Feedback to stakeholders	• Little health system infrastructure required • Flexible to different public health events • Sensitive to serious outbreaks	• Etiology is rarely identified without laboratory capacity • Varying levels of technological and human capability required in detecting outbreaks, but laboratory and epidemiological resources required for determining etiology and source
Indicator-based surveillance				
Disease notification (Borgdorff and Motarjemi, 1997)	• Identify outbreaks • Monitor disease trends	• Routine reporting, data collection, and analysis	• Legal requirement for diseases/conditions to be reported	• Underreporting • Etiology is rarely identified without laboratory capacity
Syndromic surveillance (Henning, 2004; John *et al.*, 2004; Paterson *et al.*, 2012; Rosewell *et al.*, 2013)	• Monitor trends of relevant clinical syndromes • Timely detection of outbreaks of highly specific conditions	• Routine detection and reporting of syndromic cases by health care providers • Timely data can allow for rapid response	• Can be inexpensive • Sensitive to serious outbreaks	• Underreporting • Etiology is rarely identified without laboratory capacity • Dependent on the size of the outbreak, data sources, syndromes used, and the healthcare provider's ability to detect and report cases
Sentinel surveillance (Singh *et al.,* 2013)	• Provide data for estimating burden • Monitor foodborne disease trends	• Well-resourced primary healthcare systems • Motivated healthcare providers • Education/training of participants • Routine reporting	• Provides data on certain pathogens when passive surveillance is not enough	• Underreporting • Etiology is rarely identified without laboratory capacity • By design, it is not representative of the entire community
Hospital diagnosis and death registration (Borgdorff and Motarjemi, 1997)	• Provide data for estimating burden • Monitor disease trends to some extent	• Hospital diagnoses and death registers • Capacity to report surveillance data from clinical settings to public health authorities	• Comparatively low resources required	• Underreporting • Poor for the detection of outbreaks • Low sensitivity • Limited food attribution ability • Not timely
Laboratory surveillance (Borgdorff and Motarjemi, 1997)	• Monitor foodborne disease trends • Identify or confirm outbreaks • Determine transmission pathways for specific hazards	• Public health laboratories (skilled personnel, equipment, reagents) • Capacity to capture, analyze, and report surveillance data	• Microbiological data • Etiological agent is isolated, which can help identify appropriate control measures	• Resource intensive • Possibility of low sensitivity • Generally only used for a selection of pathogens

(*continued*)

Table 1 (Continued)

	Minimum capabilities	*Minimum requirements*	*Advantages*	*Challenges*
		• External quality assurance programs are required to ensure that laboratory results are comparable across a country, regions, and internationally		
Antimicrobial surveillance (Fashae *et al.*, 2010; Lee and Wakabayashi, 2013; Vandenberg *et al.*, 2010)	• Detect antimicrobial resistance in humans, animals, and food sources • Monitor antimicrobial resistance trends	• Public health laboratories, with antimicrobial testing abilities • Capacity to capture, analyze, and report surveillance data	• Microbiological data • Helps direct policy on antimicrobial prescribing	• Resource intensive • Generally only used for a selection of pathogens
Integrated food chain surveillance (Borgdorff and Motarjemi, 1997; Vandenberg *et al.*, 2010; Mensah *et al.*, 2012; WHO, 2014b)	• Determine transmission pathways for specific hazards • Identify or confirm outbreaks • Monitor foodborne disease trends • Monitor risk factors to inform public health interventions for targeted foods or food practices	• An adequate healthcare infrastructure that allows clinical specimens to be properly collected and laboratory tests to be performed as part of routine patient care • Food consumption data to establish the design of the system and prioritize pathogens, animals, and foods to be tested • Established laboratory facilities • Trained/dedicated personnel • Cross-sectoral sharing of and integration of data • Capacity to capture, analyze, interpret, and report surveillance data multidisciplinarily • Collaborative multisector response	• Source attribution is possible • Etiological agent is isolated from human, food, and animal, which can help identify appropriate control measures Formation of networks among microbiologists, epidemiologists, and food safety regulators	• Resource intensive • Ensuring harmonization among laboratories • Depends on the strength of data management and reporting at a national level • Comparisons between countries can be difficult • Disease-specific

One example of a simple and useful syndromic surveillance system is a mobile phone–based system in Papua New Guinea; however, an evaluation showed that feedback and subnational involvement in the system were weak and limited resources for laboratory support remain an issue (Rosewell *et al.*, 2013). Another example is an inexpensive, ''low-tech'' manual syndromic surveillance system implemented in the North Arcot District of India. Physicians send a postcard to the District health office to report a clinical diagnosis of any disease they deem important in order to facilitate rapid detection of possible outbreaks (John *et al.*, 2004). Issues were faced when trying to scale up this program to a national level (May *et al.*, 2011). It is also important to note that syndromes most often included are ''diarrhea,'' ''watery diarrhea,'' and ''bloody diarrhea,'' which could suggest foodborne disease, but syndromic surveillance has very low specificity, requires surveillance staff to suspect foodborne disease, and further investigation of increased cases is needed to determine whether it is a foodborne disease event (Borgdorff and Motarjemi, 1997). The ability of syndromic surveillance to detect outbreaks is also dependent on a number of factors such as size of the outbreak, data sources and syndromes used, and the healthcare provider's ability to detect and report cases (Henning, 2004).

Sentinel surveillance

As data are often actively collected in sentinel surveillance, motivation of staff at sentinel sites is a crucial aspect for complete and high-quality data (Borgdorff and Motarjemi, 1997). An example of this type of surveillance is where clinicians in selected, or sentinel, hospitals or clinics collect and report data on diarrheal illnesses that are likely to be representative of the occurrence of the syndrome in a larger community or population. Another example of sentinel surveillance in a high-income setting is the U.S. Centers for Disease Control and Prevention's FoodNet—an active surveillance network that functions in 10 sentinel sites across the country and covers 15% of the U.S. population. The sentinel nature of FoodNet has been useful to report on specific foodborne disease trends, such as increasing incidence in *Salmonella enterica* and identifying sources of geographic variation of *Campylobacter* incidence (Ailes *et al.*, 2012; Chai *et al.*, 2012). FoodNet is a complex system that provides a sentinel representation of the United States and relies on the capacity of laboratory-based surveillance.

Sentinel surveillance requires well-resourced primary healthcare systems and selected primary health centers (Borgdorff and Motarjemi, 1997). However, sentinel surveillance through sentinel provinces or states can be effective in resource poor settings if there is an investment at the site level (Engels *et al.*, 1995; Qu *et al.*, 2012; Zhang *et al.*, 2014). A major challenge of sentinel surveillance is that without laboratory confirmation of disease etiology, the capabilities of the system are restricted to detecting syndromes. There is limited published evidence of evaluations of sentinel surveillance systems used without laboratory testing capacity.

Hospital diagnosis and death registration

Hospital diagnoses and death registration can to some extent indicate disease trends and determine the magnitude of the public health problem (Borgdorff and Motarjemi, 1997). Hospital and death data have been used in studies estimating the burden of foodborne diseases (Scallan *et al.*, 2011). Relatively low administrative resources are required, but the more comprehensive hospital diagnosis and death registers produce better data. Coding issues remain a challenge even in comprehensive registers (Frenzen, 2004). Challenges of this type of passive surveillance are that it has limited capabilities in attributing sources of foodborne disease, there is a significant amount of underreporting, and sensitivity is low. In addition, there is often a large proportion of unspecified gastroenteritis, where a specific pathogen has not been identified (Borgdorff and Motarjemi, 1997), and only those who can access the healthcare system are included, creating a bias towards those who can afford to access it and to severe cases. Data flows for hospital diagnosis and death registration are too slow to assist health agencies in detecting outbreaks or trends and have little impact on immediate public health actions.

Laboratory-based surveillance

Laboratory-based surveillance is a key part of foodborne disease surveillance globally. It is used in both high-income (Gossner *et al.*, 2012; Taylor *et al.*, 2013) and middle- and low-income (Vandenberg *et al.*, 2010; Deng *et al.*, 2012; Vinas *et al.*, 2013) countries to detect foodborne disease trends, identify and confirm outbreaks, and determine transmission pathways for specific pathogens (Borgdorff and Motarjemi, 1997). A challenge of laboratory-based surveillance is that it is difficult to cover all potentially foodborne pathogens, as coverage may be more comprehensive for some agents than for others. Issues such as cost, trained staff, and clinical awareness can serve as barriers to laboratory-based surveillance. Also, it is important for laboratories to participate in a quality management system, including external quality assurance processes, to ensure that the data quality is high and the results are comparable.

Laboratory-based surveillance of nontyphoidal *Salmonella* infections in Guangdong, China in 2009 highlights advantages and challenges of laboratory-based surveillance. This program serotyped and tested *Salmonella* isolates for antimicrobial susceptibility and molecular subtyping patterns and initiated epidemiological investigations into a unique *Salmonella* Typhimurium strain affecting infants (Deng *et al.*, 2012). However, the surveillance and epidemiological investigation in Guangdong was limited by low sensitivity for laboratory-confirmed *Salmonella*, with few hospitals sending in specimens, case definition difficulties, and a low isolation rate (Deng *et al.*, 2012). Deng *et al.* (2012) recommend enhancing surveillance in Guangdong by combining both human and animal testing and harmonizing epidemiology, clinical, and laboratory capabilities, which may help determine transmission pathways.

Laboratory-based surveillance alone cannot determine probable routes of transmission. In order to identify food, water, or animal exposures associated with foodborne disease infection, the necessary resources to conduct outbreak investigations, hypothesis-generation through interviewing cases, or applied research studies, such as source attribution are required (Deng *et al.*, 2012). Other challenges for laboratory-based surveillance, particularly in low-income countries, is the need for expensive equipment and experienced laboratory staff (Mensah *et al.*, 2012). The sensitivity of laboratory-based surveillance for detecting outbreaks can be dependent on the speed data can be collected and analyzed (Busani *et al.*, 2006). In addition, although foodborne disease can be caused by many pathogens and agents, laboratory-based surveillance programs usually only focus on a few of those pathogens (Cohen *et al.*, 2010).

As foodborne diseases are not limited by borders, national and international laboratory-based surveillance networks have been established (ECDC, 2005–2014; Swaminathan *et al.*, 2006; Cohen *et al.*, 2010; Li *et al.*, 2012). These national and international networks allow rapid communication across countries on foodborne disease outbreaks, and are often based on national sentinel surveillance (Busani *et al.*, 2006). The PulseNet network is one example of this with independent national networks, such as PulseNet China, which was established in 2004 and has now become a national pathogen surveillance platform for bacterial infectious disease (Li *et al.*, 2012), forming PulseNet International. Cohen *et al*. (2010) report on the establishment and progress of the Middle Eastern Consortium on Infectious Disease (MECIDS), a network aimed at developing an enhanced foodborne disease surveillance system for *Shigella*, *Salmonella*, and *Brucella* between Jordan, the Palestinian Authority, and Israel. MECIDS has promoted regular reporting, strategic planning, trust, and collaboration on foodborne and other diseases in the region, as well as provided useful data for disease burden estimates (Cohen *et al.*, 2010). Establishing the network required extensive resources including training and advanced means of electronic communication. Challenges included differences in sensitivity and representativeness between countries and the significant lag time between the different stages of data collection from sentinel laboratories until characterization of isolates and reporting, which has prevented the use of data for real-time interventions and comparisons at regional levels (Cohen *et al.*, 2010).

Surveillance of antimicrobial resistance

Due to the widespread use of antibiotics in animal production and human medicine, antimicrobial resistance has become an important issue for many pathogens transmitted via food (Busani *et al.*, 2006). Antimicrobial testing for foodborne pathogens is undertaken in many parts of the world (Bhatta *et al.*, 2007; Fashae *et al.*, 2010; Mensah *et al.*, 2012; Zaidi *et al.*, 2012; DANMAP, 2013). Comparisons between countries is difficult, with only data from EU countries, the United States, and Canada able to be compared because among other countries there are differences in production systems, sampling sites, procedures, and antimicrobial agents tested (WHO, 2013). Despite comparison difficulties, antimicrobial surveillance can monitor disease trends and provide evidence to help regulate antibiotic use in animals.

A qualitative study of key informants in the WHO Western Pacific region on antimicrobial resistance policy revealed that although antimicrobial resistance was recognized as a problem, surveillance was often seen as weak and fragmented where present, and laboratory capacity was felt to be insufficient across all countries interviewed (Lee and Wakabayashi, 2013). The majority of key informants stressed the need for national and local plans for antimicrobial resistance surveillance, as well as increasing the number of monitoring laboratories (Lee and Wakabayashi, 2013). Laboratory facilities with skilled personnel, sufficient equipment, media, reagents (Borgdorff and Motarjemi, 1997), and antimicrobial testing ability, as well as analytical and reporting capacity are required at minimum for antimicrobial surveillance.

Integrated Food Chain Surveillance

Integrated food chain surveillance has the capability to help assess the magnitude of the food safety problem, define priorities for action, establish transmission pathways and food sources, provide different control options, define targets along the food chain, and measure the success of food safety interventions (Havelaar *et al.*, 2007). Integrated food chain surveillance systems are in place in some high-income countries (Hald *et al.*, 2005; David *et al.*, 2011; Galanis *et al.*, 2012; WHO, 2014b). Data from the integrated system improves the scientific basis for implementing management measures and performing impact assessment and risk analyses (David *et al.*, 2011). An additional advantage of integrated food chain surveillance is that the data can be used for source attribution, allowing food sources to be identified for a few specific pathogens (Hald *et al.*, 2004; David *et al.*, 2013). One evaluation identified the critical elements for the success of an integrated system as the following: dedicated people, cross-sectoral sharing and integration of data, multidisciplinary analysis and interpretation of findings, and collaborative multisectoral response (Galanis *et al.*, 2012). Integrated food chain surveillance is resource intensive as it requires harmonized laboratory testing capabilities at each point along the food chain. Even high-income countries have faced challenges from a lack of resources and infrastructure to sustain integrated food-chain surveillance programs (Galanis *et al.*, 2012).

There are some examples of ad hoc studies that have examined microbial contamination at each stage along the food chain in middle- and low-income countries that serve as examples of the promise of elements of integrated surveillance in these settings. In one study in Thailand, *Salmonella* isolates from humans, animals and foods sent to the National *Salmonella* and *Shigella* Centre in Bangkok from 1993 to 2002 were analyzed (Bangtrakulnonth *et al.*, 2004). While nonhuman sources were not systematically surveyed, the analysis identified trends and showed likely food and water sources of different *Salmonella* serovar infections (Bangtrakulnonth *et al.*, 2004). This shows some of the valuable results possible if resources were available for a systematic national integrated food chain surveillance system, such as providing evidence on disease trends and identifying high-risk foods, vulnerable groups, and foodborne transmission pathways for *Salmonella*. Similarly, an integrated food chain surveillance network in Mexico has provided evidence for the magnitude of certain foodborne disease pathogens (*Salmonella*, *Campylobacter*, and *Escherichia coli*), identified high-risk foods, and determined foodborne transmission pathways (Zaidi *et al.*, 2008, 2012). In particular, the data highlighted sanitary infrastructure weaknesses in certain regions, which helps support food safety policy (Zaidi *et al.*, 2008). While the data from Mexico's integrated surveillance network emphasize the need for ongoing integrated and antimicrobial surveillance, Zaidi *et al.* (2012) assert that the cost and technical skill needed for characterizing large numbers of isolates makes molecular methods unfeasible for Mexico and most low- to middle-income countries in the long term. Furthermore, Zaidi *et al.* (2012) believe that the cost is not justified if the burden of a pathogen is low.

The WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (WHO, 2013) provides guidance on surveillance and monitoring approaches for bringing together laboratory-based and antimicrobial data from across the food chain. Minimum requirements for an integrated antimicrobial resistance monitoring system include adequate healthcare infrastructure, food consumption data, established laboratory facilities, and trained personnel (WHO, 2013).

The Global Foodborne Infections Network, a capacity-building program that promotes integrated, laboratory-based surveillance with the aim to strengthen surveillance, strengthen the control of major foodborne diseases, and to contribute to the global effort of containment of antimicrobial resistance in foodborne pathogens (WHO, 2014b), has supported antimicrobial surveillance projects in Cameroon, Mauritius, Democratic Republic of the Congo, Nigeria, and Ethiopia, which largely focused on *Salmonella* (Mensah *et al.*, 2012). These projects succeeded in bringing microbiologists and epidemiologists from various sectors together and created the opportunity to build capacity and informal networks. Mensah *et al.* (2012) identified challenges in strengthening laboratory and antimicrobial resistance surveillance in Africa, including a lack of equipment and human resources in laboratories; underutilization of certain laboratories and lack of synergy among laboratories; inadequate human and financial resources available for food safety and foodborne disease surveillance; inefficient use of resources; and limited data reporting.

If the minimum appropriate resources are not available, it could lead to an unsustainable integrated system. The WHO Advisory Group offers further requirements for a sustainable integrated antimicrobial program over time, such as ''sustained political and financial support arising from a recognition of the public health importance of surveillance'' and ''a continuous process of program review and enhancement'' (WHO, 2013). As establishing or improving sustainable integrated food-chain surveillance systems is resource intensive, it may be difficult in resource-poor settings.

Conclusions

Foodborne disease surveillance aims to reduce the burden of illness. There are a number of different approaches that can be taken to achieve this aim (Table 1). Countries must decide on the objectives of their system and then identify appropriate approaches to meet the objectives. The approaches require varying capacities and result in different data (informal, traditional, and integrated), capabilities, advantages, and challenges. As countries strive to improve their surveillance systems, they may consider a tiered approach, where they start with detecting outbreaks via EBS, then strengthen IBS, and finally move towards integrated food-chain surveillance. Each of these levels on the spectrum requires more resources and is progressively more complex, resulting in an enhanced capacity to control and detect disease (Chiller *et al.*, 2005). Existing systems should be regularly evaluated and all available information should be reviewed (Borgdorff and Motarjemi, 1997; Chiller *et al.*, 2005). In addition, resources must be available in the long term to achieve sustainable improvements in surveillance (WHO, 2013).

A limitation of this review is that evidence published in languages other than English or not available online were excluded from this review, which excludes many national guidelines. In addition, potentially applicable evidence could have been missed; however, we conducted a comprehensive search to try to minimize this possibility.

No single foodborne disease surveillance system is likely to provide all the required information, so a combination of approaches, along with data synthesis and critical interpretation of findings must be used for good public health decision-making (Borgdorff and Motarjemi, 1997).

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