Precautions against Biological and Chemical Terrorism Directed at Food and Water Supplies

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SYNOPSIS

Deliberate food and water contamination remains the easiest way to distribute biological or chemical agents for the purpose of terrorism, despite the national focus on dissemination of these agents as small-particle aerosols or volatile liquids. Moreover, biological terrorism as a result of sabotage of our food supply has already occurred in the United States. A review of naturally occurring food- and waterborne outbreaks exposes this vulnerability and reaffirms that, depending on the site of contamination, a significant number of people could be infected or injured over a wide geographic area. Major knowledge gaps exist with regard to the feasibility of current disinfection and inspection methods to protect our food and water against contamination by a number of biological and chemical agents. However, a global increase in food and water safety initiatives combined with enhanced disease surveillance and response activities are our best hope to prevent and respond quickly to food- and waterborne bioterrorism.

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The current fascination with the specter of biological or chemical terrorism is fueled by high-profile Iraqi and Russian defectors who have provided detailed information on the construction of biological and chemical weapons, admixed with the continuing media interest in lethal infectious diseases. The focus of much of this concern has been the threat of biological agents that can be disseminated as small particle aerosols and cause casualties potentially in the millions. These scenarios tend to ignore that terrorism using biological or chemical agents has already occurred, and that food, water, and product tampering have been the common mechanisms for these acts. Moreover, these acts of terrorism have used agents such as *Salmonella* or cyanide which, while relatively mundane, have the potential to cause casualties in the hundreds of thousands.[1,2]

The use of biological or chemical agents during war encompasses a restricted range of agents that have been turned into weapons, usually for aerosol transmission, for specific tactical or strategic advantages. In contrast, for this article, biological or chemical terrorism refers to the deliberate use of biological or chemical agents to harm civilian populations. This includes a large number of agents that are scenario-dependent but are mainly restricted by their availability, feasibility for the intended use, and deliverability. Several examples targeting food and water are documented. The incidental use or threat of use of a biological or chemical agent to commit a crime or extort money is referred to as a biocrime or bioextortion and is not considered a bioterrorist act. There have been numerous such activities.[1]

It is impossible to provide a global perspective on the potential vulnerability of our food and water to deliberate sabotage. Food and drinking water in industrialized countries are generally very safe for consumption and are becoming more so every day. However, the centralization of food production and distribution and water distribution in the United States gives food and water a unique susceptibility to deliberate sabotage intended to affect a large population. The potential size of an outbreak associated with natural or intentional product contamination is likely to increase as the point of contamination gets closer to the site of production or distribution. This concept can be captured in the concept of a disease bandwidth: more people likely to be affected corresponds to a broader bandwidth.

Aside from the potential for biological or chemical terrorist incidents to cause morbidity and mortality, there are immense economic implications for these incidents even after a relatively minor episode. Moreover, these implications may constitute the major intended damage for an intentional contamination of a product. In 1978, in an effort to damage Israel's economy, a group claimed responsibility for mercury-sabotaged citrus fruit in several European countries, which led to the hospitalization of a dozen children in Holland and West Germany. The alleged lacing of Chilean grapes with minute quantities of cyanide in 1989 led to the quarantine and recall of all Chilean fruit in the United States. The magnitude of recent recalls of meat products in the United States also shows the potential economic impact of large-scale food contamination. Although not related to an intentional act of sabotage, a US company recalled 30 million pounds of frankfurters and luncheon meats in 1998 because of possible contamination with *Listeria* bacteria. The parent company closed the plant and estimated that the recall cost US$50–$70 million. The recent experience with threatened biological incidents due to alleged exposure to anthrax spores provides a framework for the immense economic and personnel resources that would be expended for similar episodes directed at our food supply.[3] This article focuses on the ability of deliberate sabotage of processed food and water to cause human disease. Bioterrorism directed at crops and animals is not discussed.

Some insights about the vulnerability of our food and water can be gleaned by examining factors responsible for the occasional natural illnesses or outbreaks associated with these items. This examination focuses on the characteristics of the microbial or chemical agents and the processes that allowed contamination and delivery to the population. The continuing emergence of novel pathogens and chemicals, new vehicles, and new modes of transmission establishes that attribution is the only factor that separates many naturally occurring outbreaks from those caused by potential bioterrorism.

FOOD

Previous examples corroborate that biological or chemical terrorists can use deliberately contaminated food as a vehicle for terrorism. One of the dozen most lethal terrorist attacks of the last century involved arsenic poisoning of several thousand SS soldiers interned in a US prisoner-of-war camp outside Nuremberg in April 1946. A vengeance group, Nakam, infiltrated the bakery that supplied bread to the camp and spread an arsenic-based poison on the loaves. It was estimated that hundreds were killed and thousands made ill.[4] More recent terrorism directed at restaurants preparing food has been documented that includes an outbreak of *Salmonella* Typhimurium among 751 people over a two-week period in September 1984. Ten salad bars at popular restaurants were deliberately contaminated by members of the Rajneesh religious cult in order to test their ability to influence voter turnout at a later local election.[5] Importantly, despite suspicions on the part of the community, a preliminary rigorous epidemiologic investigation concluded that the contamination was not likely to have been deliberate because: (*a*) no one claimed responsibility, (*b*) no motive was apparent, (*c*) law enforcement failed to establish a pattern of unusual behavior, (*d*) no disgruntled employee was identified, (*e*) there were repeated attacks of illness, (*f*) a few employees were ill before patrons, (*g*) no such event had been previously reported, (*h*) other hypotheses appeared more likely, and (*i*) the source was not manifest. This line of reasoning exemplifies the difficulty in differentiating a natural from an intentional outbreak.

Less dramatic but well-documented incidents are better characterized as biocrimes. From 1964 to 1966, several outbreaks of typhoid fever and dysentery in Japanese hospitals were traced to food and beverages contaminated by a research microbiologist, who later infected family members and neighbors. More than 100 people were affected, with four deaths; the purpose of the sabotage may have been to obtain clinical samples for a doctoral thesis.[1,6] Another malicious tampering with food was the contamination of a festive meal with embryonated ova of *Ascaris suum*—a large roundworm infecting pigs—during the Winter Carnival in 1970; four McGill University students infected the food.[7] In October 1996, a disgruntled laboratory employee at a Dallas hospital deliberately contaminated assorted commercially prepared muffins and doughnuts by sprinkling *Shigella dysenteriae* type 2 in the staff break room, causing illness in 12 people.[1,8] Targeted political assassinations or murders, such as the death of nine Russian soldiers and five civilians following the ingestion of cyanide-laced champagne that had been poisoned by the Tajik opposition at a New Year's celebration in 1995, are too numerous to recount and have been reported for centuries. Numerous hoaxes of threatened biological agent contamination of our food supply have also been investigated by security agencies worldwide.

Of course, natural contamination of food can occur during production, processing, retail distribution, food preparation, and consumption. Microbial contamination of food generally originates from animal feces, environmental organisms, or the biological flora of food handlers. Although most contamination is likely to occur at the food preparation stage in a food service establishment or home, a review of natural outbreaks shows that there are many vulnerable points for deliberate sabotage along the continuum from farm to table (Table 1).

In recent years, products have increasingly been distributed from central facilities, a development that has markedly increased our risk for large outbreaks.[9] In 1994, a large common-vehicle outbreak in the United States affected 224,000 individuals in 41 states with *Salmonella* enteritidis due to an ice cream pre-mix cross-contaminated in a liquid tanker truck which had previously transported liquid, unpasteurized eggs.[10] From early August 1998, through January 6, 1999, at least 79 illnesses caused by a rare strain of the bacterium *Listeria*

Table 1. List of infectious and communicable diseases that are transmitted through handling the food supply and the methods by which such diseases are transmitted

I. Pathogens often transmitted by food contaminated by infected persons who handle food
Calciviruses (Norwalk and Norwalk-like viruses)
Hepatitis A virus
Salmonella typhi
Shigella spp.
Staphylococcus aureus
Streptococcus pyogens
II. Pathogens occasionally transmitted by food contaminated by infected persons who handle food, but usually transmitted by contamination at the source or in food processing or by non-foodborne routes
Campylobacter jejuni
Cryptosporidium parvum
Entamoeba histolytica
Enterohemorrhagic *Escherichia coli*
Giadia Lambia
Nontyphoidal *Salmonella spp.*
Rotavirus
Taenia solium
Vibrio cholerae 01
Yersinia enterocolitica
III. Additional pathogens usually transmitted by contamination at the source, in food processing, or by non-foodborne routes
Bacillus cereus
Listeria monocytogenes
Vibrio parahaemolyticus
Vibrio vulnificus
Cyclospora cayatenensis

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monocytogenes, serotype 4b, were reported by 17 US states; hot dogs and possibly deli meats produced under many brand names by one manufacturer were the vehicle of transmission.[11] *Salmonella* Blockley (group C2C3, antigenic type 6,8:k 1,5), a serotype that rarely infects humans, was the source of a European-wide outbreak in 1998 that included Greece, England and Wales, Austria, Belgium, Sweden, Finland, and Germany. Natural outbreaks can also be associated with significant morbidity and mortality. For example, an outbreak of listeriosis associated with soft cheeses in Los Angeles in 1985 led to the death of 48 people; an *Escherichia coli* 0157 outbreak in 1996 affected more than 400 people and killed 17 people in central Scotland who consumed contaminated meat from a butcher's shop in the town of Wishaw.[12,13] Many of these episodes could just have easily been caused by the malicious addition of the biologic agent or toxin in the described product.

The broader distribution of food products has been coupled with an increasing globalization of food production. Seasonally, more than 75% of fresh fruits and vegetables are imported, and 60% of seafood eaten in America comes from abroad.[14] Outbreaks of cyclosporiasis in North America in the spring of 1996 and of 1997 were linked to Guatemalan raspberries; the mode of contamination of the raspberries was not identified for any of these outbreaks.[15] In July and August of 1997, an outbreak of Norwalk virus in Canada affecting approximately 300 people was linked to raspberries from Slovenia, with evidence that this was also part of a multi-focus outbreak in Europe. During August 1991, three cases of cholera in Maryland were associated with the consumption of frozen coconut milk imported from Thailand.[16] In March 1997, a total of 151 cases of hepatitis A among students or staff of schools in four different school districts were reported in Calhoun County, Michigan; frozen strawberries that were originally picked in Mexico and packaged in California were implicated.[17] Between December 1, 1994, and January 31, 1995, *Salmonella* Agona PT 15 infections increased abruptly in England and Wales concurrent with a large outbreak in Israel involving over 2,200 people for more than five months; the outbreak was traced to a popular children's kosher savory snack imported from Israel. Additional cases were identified in the United States and France.[18] In 1989, four outbreaks of staphylococcal food poisoning in the United States were associated with eating mushrooms canned in the People's Republic of China.[19] Similar international outbreaks have been traced to Italian chocolate exported to England and Wales, and to Australian bean sprouts exported to Finland and Sweden.[20,21]

The concern about food adulteration is not limited to infectious agents. Chemical contamination may also occur and is not restricted to pesticides, toxins, or cyanide but includes trace heavy metals, nonmetal ions (e.g., fluorine, bromine, and iodine), food additives (e.g., bromate, glutamate, nitrite, salicylate, sorbate, and sulfite), detergents (e.g., anionic detergents and quaternary amines), and fat-soluble vitamins. Pediatric lead poisoning in the United States has been reported in association with eating imported candy and foodstuffs.[22] The largest pesticide-related foodborne outbreak in the United States occurred in 1985, when 1,373 people reported becoming ill after eating watermelons grown in soil treated with aldicarb.[23] Several plant toxins, such as phytohemagglutinin, may survive cooking and cause gastrointestinal symptoms following consumption of affected red kidney beans.[24] Fungi produce heat-stable tricothecene mycotoxins called vomitoxin. In China, 35 outbreaks affecting 7,818 people from 1961 to 1985 were attributed to consumption of foods made with moldy grain. Corn and wheat samples collected during two of these outbreaks had higher levels of deoxynivalenol (DON) than those collected at other times.[25] In India in 1987, 97 people became ill after consuming wheat products following heavy rains. DON and other tricothecene mycotoxins were detected in the implicated wheat products. Other short-acting toxins include plant toxins (e.g., alkaloids such as solanines, opiates, ipecac, and ergot; lectins such as phytohemagglutinin; and glycosides); and mycotoxins (e.g., DON, acetyl-deoxynivalenol, and other tricothecenes). In June 1999, Belgium banned the sales of eggs and chickens because of high levels of dioxin that originated from contaminated feed. These poisonings, including radiologic contamination, present unique challenges for detection and surveillance and highlight the potential damage from simply deliberately mimicking natural outbreaks.

WATER

Drinking water can become contaminated at the original water source, during treatment, in the pipes that distribute water from a treatment facility to homes and businesses, or in containers. Surface water (river or lake) can be exposed to acid rain, storm water runoff, sewage overflow, pesticide runoff, and industrial waste. This water is cleansed somewhat by exposure to sunlight, aeration, and microorganisms in the water. Groundwater (aquifer) generally takes longer to become contaminated, but the natural cleansing process also may take much longer since it moves slowly and is not exposed to sunlight, aeration, or aerobic (requiring oxygen) microorganisms. Groundwater can be contaminated by disease-producing pathogens, leachate from landfills and septic systems, careless disposal of hazardous household products, agricultural chemicals (fertilizers, pesticides, herbicides), industrial chemicals, and leaking underground storage tanks. Water distribution systems contain living microorganisms and nutrients that enter a system with raw water during water treatment failures or from leaks, cross-connections, and back-flows. Bacterial growth may also occur at or near the pipe surfaces (biofilms), the interface with suspended particulates, and within the water itself. Besides microbes, other contaminates occurring in drinking water can include: (*a*) organics (trihalomethanes and other disinfection by-products), which are formed when chlorine and other water disinfectants combine with naturally occurring organic matter; pesticides, including herbicides, insecticides, and fungicides; and volatile organic chemicals; (*b*) inorganics (arsenic, barium, chromium, lead, mercury, and silver); and (*c*) the radionuclides radon (RN^{222}), radium (Ra^{226}, Ra^{228}), and uranium (Ur^{238}). Many of these chemicals, such as arsenic, are documented human carcinogens.

Three primary sets of standards are used to establish safe drinking water throughout the world. They include the Safe Drinking Water Act in the United States, European drinking water standards, and World Health Organization guidelines. Use of these standards has vastly improved the quality of drinking water, which once was the source of widespread outbreaks of microbial origin. However, the standards are not uniformly applied, and the raw water pollution levels vary so greatly that the quality of processed drinking water worldwide cannot be collectively described. In the United States, about 90% of the population is served by federally regulated public water-supply systems.[26] Approximately one-half of the public supply goes for commercial use. Domestic water use includes water for normal household purposes such as drinking and food preparation; the vast majority of water, however, is used for flushing toilets, bathing, washing clothes and dishes, and watering lawns and gardens. Drinking water sources vary across communities, but in the United States, approximately 53% of all drinking water comes from groundwater sources (wells); the remaining 47% comes from surface water sources (rivers, lakes, and reservoirs). Each person drinks about , depending on the climate, 120–160 gallons of community tap water directly as beverage per year. Bottled water consumption in the United States has increased tenfold since 1976 to a current level of nearly four million gallons per year. In some cities, 15% to 30% of residents report that they drink only bottled water for reasons that range from the bad taste of tap water to concerns about chemicals or infectious agents in tap water. Water usage patterns vary among countries, as does the percentage of water used for drinking.

Deliberate sabotage of industrialized water supplies is possible, but there is no evidence it has ever occurred, despite countless threats to municipal water supplies. There are press reports that Kurdish rebels who tried to poison the water supply of a Turkish military base with potassium cyanide in 1992. In 1973, a German biologist threatened to contaminate water supplies with *Bacillus anthracis* and botulinum toxin unless he was paid US$8.5 million. Although contamination of drinking sources was a common wartime measure even up to the time of the US Civil War, modern water sanitation methods present major obstacles to those who wish to "poison the water well." Five factors are cited as safeguards to deliberate contamination of water supplies: (*a*) dilution; (*b*) specific inactivation from chlorine, ozone, or other water disinfectants; (*c*) nonspecific inactivation by such factors as hydrolysis, sunlight, and microbes; (*d*) filtration; and (*e*) the small quantity of water (approximately 1.0 to 1.5 L depending on the weather and region of the world) that is actually ingested directly from the tap or other water supply. Specifically, these factors should be sufficient to inactivate most of the usual waterborne agents. *Cryptosporidium* is the major exception because of its low infectious dose, high resistance to water disinfectants, and long survival in water. In addition, there is a paucity of data for other commonly cited agents of bioterrorism directed at treated water supplies (Table 2). This table also does not factor in the efficacy of chloramine, which is beginning to be used as a residual disinfectant in many US water utilities and may have a slower reaction rate than free chlorine. Even fewer assurances can be provided for unfiltered and/or non-disinfected water supplies.

For most agents, intentional microbial contamination of source-water lakes and rivers poses only a small risk because of the previously cited factors. The most recent US Environmental Protection Agency guidelines for municipal water systems using surface water recommend residual chlorine concentrations of ≥ 0.2 mg/L, and a maximum residual disinfectant level of 4 mg/L. However, chlorine is maintained at the lowest level that will keep the system in compliance with microbial requirements to minimize production of trihalomethanes.[27] Contamination of wells and surface water at utility intakes is of somewhat greater concern, especially in the two-thirds of municipal water supplies that use groundwater supplies that remain

Table 2. Threat potential of biological agents to drinking water

Agent	*Water threat*	*Stable in water*	*Chlorine tolerance*
Bacillus anthracis	Yes	2 years (spores)	Spores resistant
Brucella spp.	Probable	20–72 days	Unknown
Clostridium perfringens	Probable	Common in sewage	Resistant
Fancisella tularensis	Yes	Up to 90 days	Inactivated 1 ppm–5 min
Burkholderia mallei	Unlikely	Up to 30 days	Unknown
Burkholderia psuedomallei	Unlikely	Unknown	Unknown
Shigella spp.	Yes	2–3 days	Inactivated 0.05 ppm–10 min
Vibrio cholerae	Yes	Survives well	Easily killed
Salmonella spp.	Yes	8 days, fresh water	Inactivated
Yersina pestis	Yes	16 days	Unknown
Coxiella burnetti	Possible	Unknown	Unknown
Rickettsia spp.	Unlikely	Unknown	Unknown
Chlamydia psittaci	Possible	18–24 hrs, seawater	Unknown
Alphaviruses	Unlikely	Unknown	Unknown
Filoviruses, arenvaviruses, bunyaviruses, flaviviruses	Unlikely	Unknown	Unknown
Variola	Possible	Unknown	Unknown
Hepatitis A	Yes	Unknown	Inactivated 0.4 ppm–30 min
Cryptosporiodium spp.	Yes	Stable weeks or more	Oocysts resistant–killed by 720 ppm for 10 min
Botulinum toxins	Yes	Stable	Inactivated 0.6 ppm–20 min
T-2 mycotoxins	Yes	Stable	Resistant
Aflatoxin	Yes	Probably stable	Resistant
Ricin	Yes	Unknown	Resistant at 10 ppm
Staph. Enterotoxins	Yes	Probably stable	Unknown
Microcystins	Yes	Probably stable	Resistant at 100 ppm
Anatoxin A	Probable	Inactivated in days	Unknown
Tetrodotoxin	Yes	Unknown	Inactivated at 0.5 ppm
Saxitoxin	Yes	Stable	Resistant at 10 ppm

Ambient temperature, 1 ppm free available chlorine (FAC), 30 minutes, or as indicated

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untreated despite continued outbreaks. Outbreaks involving groundwater have occurred after the introduction of as little as an estimated 20 g of infected feces.[28] The number of people affected by an attack on the distribution system would depend on where the system was breached; that is, the closer the breach was to the treatment plant or wellhead, the greater the number of people affected. Thus, the disease bandwidth narrows from the treatment plant, through various holding tanks, to the tap in a person's home.

Although water purification plants can effectively kill most bacteria, treatment processes that rely solely on chlorine or chloramine disinfection and/or conventional filtration (i.e., do not include reverse osmosis or ozone) are ineffective against toxins, chemicals, and some parasites. Activated carbon (added to filter media to control taste, odor, or chemical problems) may be effective against some organic toxins but is not widely used in US water treatment facilities. A review of natural outbreaks confirms that parasites such as *Cryptosporidium* are able to overwhelm all of the conventional water treatment barriers.

The potential for water to serve as a vehicle for an agent and to cause mass casualties in the modern era was verified by the largest documented waterborne disease outbreak in the United States since recordkeeping began in 1920.[29–31] An estimated 403,000 people developed cryptosporidiosis in Milwaukee in 1993—of whom 4,400 were hospitalized and at least 54 died—in association with water obtained from a municipal water plant. Although the treated water met all the state and federal quality standards that were then in effect, *C. parvum* oocysts were able to get through the treatment system in sufficient numbers to infect a large proportion of the population served. Information based on mathematical modeling suggested that some individuals might have become infected when exposed to only one oocyst.

The biggest threat to city populations may be from large municipal water systems that are no longer maintained or poorly operated. From January 1996, to July 1997, some 8,901 cases and 95 deaths from typhoid fever occurred in Dushanbe (population: 600,000), Tajikistan, when the chlorination of the municipal water supply ceased for lack of funds.[32] Smaller outbreaks have also been associated with Norwalk-contaminated ice.[33] Outbreaks of cryptosporidiosis, *E. coli* O157:H7, and leptospirosis associated with swimming in contaminated pools demonstrate the ease with which recreational water could also be used as a vehicle of bioterrorism, especially at water parks that have thousands of visitors per day.

Bottled waters are not free from the risk of accidental or intentional contamination. As with tap water, the location and quality of source water as well as the water treatment processes used by bottled water companies can significantly reduce or increase the risks of contamination. Reverse osmosis treatment of water before bottling is one of the most effective barriers against toxins and microbial contaminants that might be in water prior to bottling. Reverse osmosis processing is less commonly used by bottlers in Europe than in the United States. The international recall of Perrier bottled water because of concerns of benzene contamination is a reminder that these widely distributed waters could be vehicles of biological or chemical agents. Milk also is a beverage, unlike tap water, that will necessarily be ingested and has been associated with a *Salmonella* Typhimurium outbreak at a state-of-the-art facility in 1985 in the United States, affecting an estimated 200,000 people.[34] However, with some exceptions, the 1999 Pasteurized Milk Ordinance and the National Conference on Interstate Milk Shipments provide adequate assurance and oversight to protect public health.[35]

PREVENTION AND CONTROL

An examination of naturally occurring disease outbreaks highlights our potential vulnerability to biological or chemical terrorism targeted at our food and water. A sophisticated terrorist organization could readily assess the disease bandwidth and points of vulnerability to introduce an agent that could adversely affect the safety or abundance of that food or water product. Our risk, therefore, may not be dissemination of a high-tech aerosol at an indoor stadium, but the anthrax spores in the community mustard and ketchup dispensers at the concession stand. The challenge of an infinite combination of agents and dissemination scenarios makes prevention of any future event difficult. As indicated above, the scale of the public health impact could be minimized by tight quality control at the central locations where products are processed. However, to detect a failure in the quality control or a contamination event more distal to the location of central processing, we must rely on effective surveillance systems to detect outbreaks and then rapidly respond.

Introduced agents could exploit the temperature, tonicity, and other physical and chemical characteristics of the food and water at the point of contamination and have activity following ingestion. They would include traditional foodborne pathogens introduced at different points in the food chain or, for truly surreptitious use, more hardy versions of expected agents. The low infectious dose for many of these agents facilitates deliberate contamination. *Salmonella* Typhimurium definitive type 104 (DT104) is multidrug-resistant. Staphylococci thrive in high concentrations of salt and sugar that other organisms cannot tolerate and elaborate a highly heat-resistant enterotoxin.[36] Norwalk-like viruses are hardy, ubiquitous, and extremely persistent in the environment, resisting disinfection and chlorination, and have caused serious gastroenteritis outbreaks.[37] Cryptosporidia are even hardier; they survive for weeks to months in cold water and require contact with 720 mg/L of free chlorine to kill them in 10 minutes. Contaminants could also include agents that are never seen as routine pathogens in a specific product but only use the product as a very efficient vector. Such agents might include hallucinogens and teratogens, as well as the use of infectious microorganisms not usually considered as traditional foodborne or waterborne pathogens.

Toxins present unique advantages for deliberate sabotage because they tend to be odorless, colorless, tasteless, and biologically active at microgram amounts; many are also heat stable. Botulinum toxin A is the most lethal substance known to humans (mean lethal dose <0.001 μg/kg). Without considering the effectiveness of dissemination, there are varying estimates that 2 oz. is sufficient to kill everybody in North America.[2] Tetrodotoxin blocks sodium conductance and neuronal transmission in skeletal muscles; it is a powerful neurotoxin that can cause death in approximately 60% of persons who ingest it.[38] Ciguatoxins are odorless, colorless, tasteless, and unaffected by either cooking or freezing.[39]

The identities of many potential agents are unknown, such as the etiologic agent for 16 outbreaks of gastrointestinal illness in approximately 1,700 schoolchildren that was associated with eating burritos in seven states in 1998.[40] Haff disease is a syndrome of unexplained rhabdomyolysis following consumption of certain types of fish; it is caused by an unidentified heat-stable toxin.[41] Prions share many properties with toxins. They are even more resistant to disinfection and can also cause foodborne disease, as exemplified by the outbreak of new variant Creutzfeldt-Jakob disease (CJD) in the United Kingdom associated with the epizootic of bovine spongioform encephalopathy and supported by animal models.[42] Prions are unique in terms of terrorism potential because of their extremely long incubation period and the difficulty of confirming infection.

Most foodborne disease surveillance is passive. The United States maintains national laboratory-based and physician-based reporting surveillance for *Salmonella*, *Shigella*, *Campylobacter*, and *E. coli* O157:H7 organisms, among others. Rapid statistical analysis of this surveillance information can detect an unusual clustering of infections by time or geographic area compared with a historic baseline, monitor secular trends, and lead to early recognition of outbreaks.[43] However, these passive surveillance systems are prone to considerable underreporting because only a small fraction of ill patients seek medical care, many clinicians do not routinely obtain stool cultures from patients with diarrhea, not all laboratories culture for certain foodborne pathogens, and not all laboratories report isolates to health officials. Approximately 20 to 100 cases of salmonellosis go unreported for each reported case.[44] Active surveillance can help to determine more accurately the burden of illness from specific foodborne pathogens, to increase the timeliness of information, and to provide a baseline against which to monitor the effectiveness of control measures. The Foodborne Diseases Active Surveillance Network (FoodNet) was designed to determine more precisely the burden of foodborne illness in the United States through active surveillance and related studies at eight sentinel sites as a collaborative project among public health authorities, the US Department of Agriculture (USDA), and the US Food and Drug Administration (FDA).[45] In addition to determining more precisely the frequency and severity of foodborne diseases that occur in the United States, the objectives of FoodNet are to provide a network for responding to new and emerging bacterial, parasitic, and viral foodborne diseases of national importance, and to identify the source of specific foodborne diseases.

Molecular typing and subtyping methods are important surveillance tools to help detect and respond to outbreaks. *Salmonella* serotyping has helped to elucidate the associations between specific serotypes and certain food vehicles, such as serotype Enteritidis and eggs, or serotype Heidelberg and chickens.[46] A newer subtyping technique, pulsed-field gel electrophoresis (PFGE), has enhanced surveillance for *E. coli* O157:H7 infections and other bacterial foodborne pathogens by helping to distinguish sporadic background infections from those that are outbreak-related, and has helped link geographically dispersed cases or outbreaks.[47–51] Recently, selected public health laboratories in the United States have established a computer network (PulseNet) to rapidly analyze and compare PFGE patterns of *E. coli* O157:H7, nontyphoidal *Salmonella* serotypes, *Listeria* monocytogenes, and *Shigella* isolates. This network has aided in the swift recognition of cases caused by strains with virtually identical DNA fingerprints, suggesting exposure to a common source, and helped to rapidly recognize potential connections among geographically dispersed cases.[52] Another example of these systems at work is the European Union–funded Salm-Net (Salmonella Surveillance Network). It used molecular analyses based on plasmid profile typing and PFGE to define a strain of *Salmonella enterica* serotype Anatum associated with the consumption of a particular brand of formula-dried milk. This milk was responsible for an outbreak in late 1996/early 1997, involving 15 infants and two relatives in the UK, and two infants in France.[53]

These surveillance activities must be coupled with robust response activities that are triggered by real-time monitoring of surveillance indicators and contacts with the medical community. For most diseases a single case may represent a public health emergency, because contaminated food may still be available to cause illness in others and herald the beginning of a large outbreak. This is especially true for botulism, which has high case-fatality if untreated, and requires a prompt investigation to provide antitoxin for administering to exposed individuals.[54] Investigative steps include a search for other suspected cases, diagnostic testing, and identification of the suspect food item or beverage. Rapid identification of the source of contamination can lead to appropriate control measures including recalling the implicated item(s), halting ongoing contamination, and assessing the disease bandwidth. This investigation also provides the epidemiologic clues to determine if the cluster was due to deliberate contamination and forms the basis for notifying law enforcement agencies. Establishing this rapid response will require a cadre of well-trained epidemiologists, preferably as part of a global network. Such networking will also be needed to stockpile certain drugs and move key treatment modalities that are in limited supply (such as botulinum antitoxin) to where they are needed.

Recent US declines in salmonellosis and campylobacteriosis parallel changes in meat and poultry slaughtering practices and processing plants, mandated by the Pathogen Reduction and Hazard Analysis and Critical Control Points (HACCP) rule of the USDA.[55] In this management system food safety is addressed through the analysis and control of biological, chemical, and physical hazards from raw material production, procurement and handling, to manufacturing, distribution, and consumption of the finished product. Prerequisite programs such as the Good Manufacturing Practices program (GMPs) are an essential foundation for the development and implementation of HAACP plans.

This process would not work for agents introduced into foods after a final, critical, control point. Even naturally, foods can become contaminated after effective pasteurization or irradiation has been successfully completed. Mechanisms designed to prevent contamination with naturally occurring pathogens may not detect those that would not normally be present in the food item. Irradiation prior to shipment of the product would reduce the disease bandwidth for microbial contamination, but will not remove chemicals or attenuate toxins and has limited effectiveness against RNA viruses. It is also neither feasible nor appropriate to individually monitor the behavior of more than 100,000 food handlers at thousands of facilities in the United States.

Current surveillance systems in the United States for detecting waterborne disease are insensitive. Less than 8% of people with a gastrointestinal illness seek medical care, and even fewer have stool specimens tested for emerging or unusual pathogens. The waterborne mode of transmission of the previously described *Cryptosporidum* outbreak and its etiologic agent went undetected for three weeks. Outbreaks involving even more unusual pathogens or toxins and smaller numbers of people would likely be missed, or water would not be considered as a likely vehicle if the terrorist did not claim responsibility.

CONCLUSION

The key to preventing illness from biological and chemical terrorism is to improve quality control and implement reasonable security measures at central production facilities, based on a vulnerability assessment. However, this is not feasible for contamination at food distribution sites such as restaurants, and may be impractical given the multitude of vulnerabilities. Therefore, assuming that all acts of terrorism will not be detected or prevented solely by improving routine food and water production processes or treatment barriers, early detection of outbreaks has the greatest potential for saving lives and limiting the scope of illness. The fundamental tenet to detecting outbreaks early is to strengthen our surveillance systems. This includes evaluating the sources of reports of infectious diseases and the requirement to report illness to public health authorities. The efficiency of those systems must also be enhanced by demanding etiologic diagnoses of more syndromes (specifically, the specific pathogens associated with diarrhea) and genetic-level characterization of the recovered agents by clinicians and laboratory personnel. We must also develop better methods for rapidly capturing data on ill people and electronically linking these data with laboratory results. These mechanisms include surveillance systems such as Foodnet in the United States or Euronet in Europe. PulseNet and SalmNet are also exciting surveillance mechanisms that allow linking of seemingly unrelated cases of culture-confirmed diarrheal illness by comparing the molecular subtype of foodborne bacterial pathogens. This enhanced surveillance will not make a substantial difference on the eventual case numbers without continued improvements in interagency communications and faster tracing of a product to a specific location, coupled with timely regulatory or law enforcement action. Even if these mechanisms do not prevent further illness, as when all the implicated food or water has been ingested, they may be the only clue to deliberate contamination, which would launch a law enforcement response to prevent additional bioterrorist actions.

Preparedness planning is critical to assess our susceptibility to deliberate contamination and to devise the most effective prevention strategies. Countries must do surveys of their particular water and food-production systems to assess the risks of contamination. These activities have the additional benefit of reducing or removing natural contaminants. For example, to prevent water sabotage, we should review waterworks systems to identify points where a saboteur could do the maximum harm. Preventive strategies could include locking service reservoirs or high-level distribution tanks with routine checks for tampering; judicious use of non-return valves for service taken from trunk mains, and, if possible, from all service connections; and maintaining positive pressure in the system at all times. Identification of the source of any outbreaks would be critical to allow immediate action to warn people not to drink the water, to flush and swab the mains, and to take other actions such as hyperchlorination, which could put an end to the spread of the agent. Another important issue is ensuring the availability of adequate safe drinking water in the event of terrorist interference with the usual water supply. Food and beverage industries can also develop plans that would reduce the risk of product contamination by adding protective barriers such as reverse osmosis, activated carbon, or UV light treatment at the point where municipal water enters such facilities.

Research is the final piece of the prevention equation that cannot be ignored. This would include a full review and understanding of the most likely organisms of concern, including infectious doses, and an evaluation of the potential health impact of selected pathogens delivered by an atypical route, e.g., oral ingestion of anthrax spores. The environmental fate of different microorganisms and chemicals that have been purported to be able to cause mass casualties when introduced into food and water must be better defined. We must also assess what food and water treatment methods are most effective against particular threats. Since the mere threat of product contamination can have a major impact, it is crucial that we develop the skills to evaluate such threats scientifically. This evaluation will require assuring the availability of diagnostics to test for these contaminants. Prevention research could develop and evaluate remote-sensing devices to detect tampering with fire hydrants, sudden losses in chlorine residual in distribution systems, or sudden changes in the turbidity of a distribution system. Other experiments could also include assessment of emergency disinfection methods that could be employed after a contamination event.

Assessing and neutralizing this threat is the domain of our law enforcement and public safety officials. Responding to the medical and community health implications of threats or the actual use of biological or chemical agents is firmly in the public health sector. As part of the planning process, the public health community must identify and take preventive measures to reduce the risk of illness and focus its efforts on those hazards that present the greatest risk. Public health agencies must have robust surveillance systems that can not only rapidly determine an increase in a specific illness or syndrome, but also initiate a prompt response (e.g., investigation to implicate the potential vehicle). This is the only way public health preventive strategies will be implemented soon enough to mitigate morbidity and mortality. This emphasizes the critical necessity to focus our preparedness efforts at the local level so that local public health and medical personnel have the appropriate tools to detect and respond to terrorism; timeliness requires that they not wait for some national or international organization to solve the problem. Expansion of surveillance systems and other preparedness efforts must be linked to additional training. In the end, we will need cooperative partnerships and coordination of activities among public health and regulatory agencies at the federal, state, tribal, and local levels as well as with other agencies responsible for biological and chemical terrorism threat reduction and safety.

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