

# Chapter 3

## FOOD, WATERBORNE, AND AGRICULTURAL DISEASES

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## INTRODUCTION

Food and waterborne pathogens cause a considerable amount of disease in the United States. The economic impact from foodborne diseases is estimated at about \$78 billion per year.<sup>1</sup> The top five pathogens that contribute to domestic foodborne illness are, *Novovirus*, *Salmonella* species, *Clostridium perfringens*, *Campylobacter* species, and *Staphylococcus aureus*.<sup>2,3</sup> Many of the common foodborne pathogens, whether bacteria, viruses, parasites, or toxins, can cause disease if purposefully introduced into water or food sources. These pathogens characteristically have the potential to cause significant morbidity or mortality, have low infective dose and high virulence, are universally available, and can be stable in food products or potable water. These agents include *Clostridium botulinum* toxin, the hepatitis A virus, *Salmonella*, *Shigella*, enterohemorrhagic *Escherichia coli* species, *Cryptosporidium parvum*,

*Campylobacter jejuni*, *Listeria monocytogenes*, and *Vibrio cholerae*, among others. Pathogens in the Centers for Disease Control and Prevention (CDC) list of biological threat agents that also may cause food or waterborne disease are *Bacillus anthracis*, *Brucella* species, staphylococcal enterotoxin B, and ricin.<sup>4</sup> The potential for nonlisted biological agents such as mycotoxins and parasites (eg, *Taenia* species) to be used in a bioterrorist event should also be considered.

This chapter provides an introduction to the far-reaching subjects of food and waterborne diseases, the potential for terrorist attacks on the food and water supply, and terrorism directed at sources of the nation's farm-to-food continuum (agricultural terrorism). For a more extensive review of these topics, readers may consult more specialized texts on food<sup>5</sup> and waterborne<sup>6</sup> diseases and agricultural terrorism.<sup>7,8</sup>

## FOODBORNE AND WATERBORNE PATHOGENS AND DISEASES

### *Bacillus anthracis*

*B anthracis* is the causative agent of two forms of foodborne anthrax: oropharyngeal and gastrointestinal. Although spores of *B anthracis* would cause the most potential harm via an aerosol release, anthrax disease is not normally perceived as having bioterrorism potential as a foodborne bacterial contaminant because the infective dose required for such an attack would be high.<sup>9</sup> However, given that the early diagnosis of gastrointestinal anthrax is difficult for clinicians who have never treated cases of this disease, a higher mortality rate than expected may result from a natural or purposeful outbreak. Anthrax spores are resistant to disinfection by contact chlorination as used by water treatment facilities, although higher levels of chlorination ( $\geq 100$  ppm) for longer contact times (5 minutes) will kill *Bacillus* spores.<sup>10</sup>

### *Clostridium botulinum*

*C botulinum* is the causative agent of botulism intoxication, of which there are three natural manifestations: classic, wound, and infant botulism. Bioterrorism use of botulinum toxin could possibly occur through inhalational intoxication, as was considered by the Aum Shinrikyo cult in Japan in 1990.<sup>11,12</sup> *C botulinum* produces the most potent natural toxin known; the human lethal dose of type A toxin is approximately 1.0  $\mu\text{g}/\text{kg}$ .<sup>13</sup> There are seven antigenic types of botulinum toxin, denoted by the letters A through G. Most human disease is caused by types A, B, and E.

Botulinum toxins A and B are often associated with home food preparation<sup>14</sup> and home canning<sup>15</sup> and pickling.<sup>16</sup> Botulism-contaminated food cannot be distinguished by visual examination, and the cook is often the first to show the toxin's effects (via sampling the food during cooking). A 12- to 36-hour incubation period is common. The incubation period is followed by blurred vision, speech and swallowing difficulties, and descending flaccid paralysis.<sup>17</sup>

The current mortality rate associated with botulism intoxication is less than 10%. Foodborne botulism mortality during the 1950s (before the advent of modern clinical therapies) was approximately 25%.<sup>18</sup> Little evidence of acquired immunity from botulinum intoxication exists, even after a severe infection. Successful treatment consists of aggressive trivalent (A, B, E) botulinum antitoxin therapy and ventilatory support. Early diagnosis is critical for patient survival. Toxin can be found in food, stool, and serum samples, which may all be used in the standard mouse model assay to test for the presence of botulism toxin.<sup>19</sup>

A controversial paper published in 2005<sup>20</sup> explored the potential for botulinum toxin contamination of the milk supply. A nine-stage dairy cows-to-consumer supply chain was examined, which accurately modeled a single milk-processing facility. The release of botulinum toxin was assumed to have occurred either at a holding tank at the dairy farm, in a tanker truck transporting milk from the farm to the processing plant, or at a raw milk silo at the plant. By the use of this model, it was predicted that 100,000 individuals could be poisoned with over 1 gram of toxin, and 10 grams

would affect about 568,000 milk consumers.<sup>20</sup> The National Academy of Sciences published this information to foster further discussion and alert authorities to dangers to the milk supply from purposeful contamination.<sup>21</sup> The paper also describes interventions that the government and the dairy industry could take to prevent this scenario. Officials at the US Department of Health and Human Services requested that the paper not be published, but the National Academy of Sciences published it anyway, convinced that the information would not enable bioterrorists to conduct an attack, and that the paper would stimulate biodefense efforts. Whether the paper's information presents a "roadmap for terrorists" by exposing vulnerabilities in food processing remains to be determined<sup>22</sup>; however, the hypothetical use of botulinum toxin placed at various points into the food supply was proposed in a fictional novel over 35 years ago.<sup>23</sup>

### *Campylobacter jejuni*

*Campylobacter*, *Salmonella*, *Listeria*, and *E coli* O157:H7 can be transmitted zoonotically from contaminated animal food sources. These bacteria species are ubiquitous and cannot be completely eliminated from the food supply. *C jejuni* is the most commonly reported bacterial cause of foodborne infection in the United States.<sup>24</sup> Chronic sequelae associated with *C jejuni* infections include Guillain-Barre syndrome<sup>25</sup> and arthritis.<sup>26</sup> Infants have the highest age-specific isolation rate for this pathogen in the United States, which is attributed to a greater susceptibility upon initial exposure and a lower threshold of seeking medical treatment for infants.<sup>24</sup> Reservoirs for *C jejuni* include wild fowl and rodents.<sup>27</sup> The intestines of poultry are easily colonized with *C jejuni*,<sup>28</sup> and it is a commensal inhabitant of the intestinal tract of cattle.<sup>29</sup> Antibiotic resistance of *Campylobacter* is a growing concern for poultry farmers.<sup>30</sup> The infective dose for *Campylobacter* is 100 to 1,000 cells, with poultry the primary source of infection in the United States.<sup>31</sup> Insect transmission by several fly species has also been documented.<sup>32</sup> There is a 3- to 5-day illness onset for campylobacteriosis and a 1-week recovery time. Immunity is conferred upon recovery, which accounts for a significantly higher incidence rate among individuals younger than 2 years of age in developing countries.<sup>33</sup>

### *Salmonella*

Salmonellosis is the second most common foodborne illness,<sup>34</sup> and contaminated food is the principal route of disease transmission.<sup>35</sup> There are over 2,400 *Salmonella* serotypes, many of which can cause gas-

troenteritis, manifested as diarrhea, abdominal pain, vomiting, fever, chills, headache, and dehydration.<sup>34,35</sup> Other diseases from *Salmonella* infections include enteric fever, septicemia, and localized infections. Poultry is a principal reservoir of the salmonellae.<sup>35</sup> Water, shellfish, raw salads, and milk are also commonly implicated as vehicles for this pathogen. In humans, the most highly pathogenic *Salmonella* species is *S typhi*.<sup>35</sup> This bacterium is the causative agent of typhoid fever, which comprises about 2.5% of salmonellosis in the United States.<sup>35</sup> The symptoms of typhoid include septicemia, high fever, headache, and gastrointestinal illness.<sup>35</sup>

During World War II, the Japanese developed biological weapons, poisoning prisoners with *S typhimurium* and many other bacteria and viruses during their experimentation, and contaminating wells with *S typhimurium* along the Russian border of Mongolia.<sup>36</sup> In September and October 1984, two large groups of salmonellosis cases occurred in The Dalles, Oregon. Case interviews by health officials associated patronage of two restaurants in The Dalles with illness, especially with food items eaten from salad bars. *S typhimurium* isolates were then obtained from clinical specimens.<sup>37</sup> The size and nature of this outbreak helped to initiate a criminal investigation, which was rarely done in conjunction with a foodborne disease outbreak. The cause of the epidemic became known when the Federal Bureau of Investigation investigated a nearby cult (the Rajneeshees) for additional criminal violations.<sup>38</sup> In October 1985 authorities found an opened vial that contained the original culture type of *S typhimurium* inside a refrigerator within the Rajneeshee clinic laboratory.

A large multistate outbreak of milk-borne salmonellosis from *Salmonella enteritica* serovar *typhimurium* occurred in northern Illinois in 1985, with more than 14,000 people reported ill and five deaths.<sup>39,40</sup> The cause of the outbreak was the accidental comingling of raw milk into the pasteurized product in a milk plant.<sup>41</sup> The contaminated milk was distributed via supermarket distribution systems, and cases were also reported in the neighboring states of Indiana, Iowa, and Michigan.<sup>42</sup> Medical treatment was complicated because the strain of *S typhimurium* involved was found to be resistant to antibiotics. Such inadvertent milk-borne contamination reinforces the potential for a ready-made vehicle for transmission of disease among a population by deliberate means.<sup>20</sup>

### *Listeria monocytogenes*

*L monocytogenes* is ubiquitous in the environment and often found in silage, water, and the environs of animal fodder.<sup>43</sup> Soft cheeses,<sup>44</sup> raw or contaminated

milk,<sup>45</sup> and contaminated refrigerated foods<sup>46</sup> are often sources of this organism. Listeriosis can result in meningo-encephalitis and septicemia in neonates and adults, and fever and abortion in pregnant women.<sup>47</sup> Fetuses, newborns,<sup>48</sup> the elderly,<sup>49</sup> and immunocompromised persons<sup>50</sup> are at greatest risk for serious illness. Listeriosis case investigations can be problematic because of the variable incubation period for illness (3 to >90 days). Large outbreaks of foodborne listeriosis have occurred, including a 1983 Massachusetts epidemic where improperly pasteurized milk was the source of the infection.<sup>51</sup> Of the 49 infections associated with this outbreak, 14 patients died.<sup>51</sup>

### *Escherichia coli*

*E coli* O157:H7 infections often originate from contamination due to a bovine reservoir.<sup>52</sup> This organism produces two verotoxins and is a significant cause of serious pediatric illness.<sup>53</sup> It can result in bloody diarrhea and hemolytic uremic syndrome, which is defined as the demonstration of three clinical conditions: (1) microangiopathic hemolytic anemia, (2) acute renal failure, and (3) thrombocytopenia.<sup>53</sup> Children younger than 5 are at greatest risk for hemolytic uremic syndrome when infected with *E coli* O157:H7 or other enterohemorrhagic *E coli* (EHEC) species, and deaths from these infections occur most often in the age ranges of 1 to 4 years and 61 to 91 years.<sup>52</sup> A major source of EHEC exposure is from consumption of and contact with beef cattle.<sup>54</sup> About 20% of the ground beef consumed in the United States is derived from culled dairy cattle, which may be an important contributor to this bacterial contamination of the food supply.<sup>55</sup> For example, during July 2002, the Colorado Department of Public Health and Environment identified an outbreak of *E coli* O157:H7 infections that linked 28 illnesses in Colorado and six other states to the consumption of contaminated ground beef products. Seven patients were hospitalized, and five developed hemolytic uremic syndrome.<sup>56</sup>

*E coli*-contaminated food items commonly result from use of cattle waste as fertilizer or other contact with cattle products. Outbreaks have occurred from exposure to various *E coli*-tainted food items, including alfalfa<sup>57</sup> and radish<sup>58</sup> sprouts, parsley,<sup>59</sup> lettuce,<sup>60,61</sup> hazlenuts,<sup>62</sup> apple cider,<sup>63</sup> unpasteurized gouda cheese,<sup>64,65</sup> raw milk,<sup>66</sup> recontaminated pasteurized milk,<sup>67</sup> prepackaged cookie dough,<sup>68</sup> and salami,<sup>69</sup> as well as through petting zoos<sup>70</sup> and environmental transmission.<sup>71,72</sup> Waterborne outbreaks of *E coli* O157:H7 have also occurred. From mid-December 1989 to mid-January 1990, 243 cases of gastrointestinal illness from antibiotic-resistant *E coli* O157:H7 occurred

in a rural Missouri township as a result of an unchlorinated water supply.<sup>73</sup> Swimming-associated outbreaks of *E coli* O157:H7 have also occurred.<sup>74,75</sup>

Other enterohemorrhagic *E coli* strains containing Shiga toxins (Shiga toxin-producing *E coli* [STEC] infections) have appeared as public health concerns, including STEC O121,<sup>76</sup> STEC O26,<sup>77</sup> STEC O145,<sup>78</sup> and STEC O104:H4.<sup>79</sup> Novel STEC strains can easily develop due to opportunistic microbial growth and spread in the food supply chain and distribution systems. The CDC *E coli* investigation page<sup>80</sup> lists current and past identified outbreaks. A recent 10-year study in Connecticut of 663 reported STEC infections demonstrated that both O157 and non-O157 STEC infection incidence decreased from 2000 through 2009, and also that O157 was the most common and clinically severe type of STEC infection.<sup>81</sup> However, in this and other studies, non-*E coli* O157 accounted for a minority of all clinically significant STEC infections.<sup>82,83</sup> Importantly, STEC O104 and O157:H7 infections are more likely to lead to hospitalization and death than other STEC serogroups, as shown by a recent 8-year retrospective cohort study of 8,400 patients in Germany.<sup>84</sup> Another recent German study demonstrated that cattle density is a risk for exposure to *E coli* O157:H7 and other STEC strains, including all major disease-causing groups (O26, O103, O111, O128, O145), but not O91.<sup>85</sup> STEC strains therefore appear to be a diverse group of organisms that demonstrate differences as well as many commonalities in exposure and epidemiology.

### *Shigella*

Humans are the major reservoir for *Shigella* and the primary source of subsequent infections.<sup>86</sup> It is thought that worldwide *Shigella*-associated illness causes about 165 million cases per year, of which fewer than 1% occur in industrialized nations.<sup>86</sup> *Shigella dysenteriae* produces severe disease, may be associated with life-threatening complications, and causes about 25,000 cases of illness each year in the United States.<sup>86</sup> Although not an environmentally hardy organism, *Shigella* is highly infectious and can be very persistent in a close community environment.<sup>87</sup> Four serogroups (A through D) cause approximately 80% of shigellosis cases in the United States. Immunity is serotype-specific.<sup>88</sup> Vaccine development has been problematic,<sup>89</sup> and the species can easily become resistant to antibiotics.<sup>90</sup> Infants and young children are most susceptible to shigellosis, attributable in part to toiletry behaviors and child care practices. The infectious dose for *Shigella* is 10 to 100 organisms, and *Shigella* contamination can cause outbreaks associated with food, water, and milk. Shigellosis has also been associated with recreational

swimming.<sup>91</sup> Shigellosis is readily transferred from person-to-person contact and through fomites<sup>92</sup>; it can also be transmitted by insect vectors (primarily flies).<sup>93</sup> There is a 1- to 3-day incubation period for shigellosis. *Shigella* organisms are shed for 3 to 5 weeks after symptoms cease, ultimately contributing to a greater person-to-person spread than with other enteric pathogens such as *Salmonella* and *V. cholerae*.

### ***Cryptosporidium***

*Cryptosporidium*, a protozoan and an obligate intracellular parasite, can cause food and waterborne illness and can also be acquired from exposure to contaminated recreational water.<sup>94-98</sup> Seroprevalence surveys indicate that about 20% of the US population have been infected with *Cryptosporidium* by adulthood.<sup>99</sup> The severity and course of infection can vary considerably, dependent upon the immune status of the individual. Intestinal cryptosporidiosis is often characterized by severe watery diarrhea but may also be asymptomatic. Pulmonary and tracheal cryptosporidiosis in humans is associated with coughing and low-grade fever; these symptoms are often accompanied by severe intestinal distress. The duration of illness in one study of 50 healthy individuals varied from 2 to 26 days, with a mean of 12 days.<sup>100</sup>

The precise infectious dose is unknown; research indicates that a range of 9 to 1,024 oocysts will initiate infection.<sup>101</sup> The pathobiology is not completely known either; however, the intracellular stages of the parasite can cause severe tissue alteration. Infected food handlers are a major contributor to disease transmission. Consequently, cryptosporidiosis incidence is higher in facilities that serve uncooked foods, such as restaurants with salad bars. Child care centers can be a problematic source of cryptosporidium infection because diarrhea in children in diapers can be difficult to contain.<sup>102</sup> A significant reservoir worldwide for *Cryptosporidium parvum* is domestic livestock, predominately cattle.<sup>103</sup> Drinking water outbreaks have affected as many as 403,000 individuals (in a 1993 outbreak in Milwaukee).<sup>94</sup> In the Milwaukee incident, the water was both filtered and chlorinated.<sup>104</sup> The organism's resistance to chlorine treatment ensures that it will remain a concern in treated potable water,<sup>105</sup> and therefore a risk to immunocompromised individuals, in whom it causes severe and chronic life-threatening gastroenteritis.<sup>106</sup>

### **Hepatitis A**

Humans are the source of the *Hepatovirus* hepatitis A virus.<sup>35</sup> Illness caused by hepatitis A is characterized by sudden onset of fever, malaise, nausea, anorexia, and abdominal discomfort, followed by jaundice.<sup>35</sup> The

infectious dose is not precisely known but is thought to be 10 to 100 virus particles.<sup>35</sup> The virus is hardy, and it survives on hands and fomites. Because viral particles are excreted in the feces during clinical illness, stringent personal hygiene is crucial to prevent disease transmission. Hepatitis A is commonly transmitted via personal contact, and fewer than 5% of all hepatitis A cases are demonstrated to have been caused by food or waterborne transmission.<sup>107</sup> Permanent immunity to hepatitis A is assumed subsequent to infection<sup>108</sup> or immunization completion.<sup>109</sup> The advent of nationwide hepatitis A vaccination programs is gradually causing a decrease in disease incidence and the susceptible population.<sup>110</sup> As a result, hepatitis A may in time cease to be a public health concern.<sup>111</sup>

The potential for hepatitis A virus transmission in drinking water was demonstrated in an outbreak among members of the varsity football team at the College of the Holy Cross in Worcester, Massachusetts, in 1969. The same water supply was used for both irrigation and potable water. Water used by firefighters to battle a blaze nearby caused a drop in water pressure, and back-siphonage brought groundwater into the football practice field's irrigation system. The groundwater had been contaminated by children infected with hepatitis A in a building immediately adjacent to the playing field. The football team members became ill after consuming the water from a faucet hooked up to this contaminated water source.<sup>112,113</sup> Although 90 of 97 players and coaches on the team became ill (93% attack rate), serologic testing performed years later revealed that only 33 had IgM anti-hepatitis A virus in serum (34% attack rate).<sup>114</sup> Because of this discrepancy, the illness may have been caused by another pathogen also present in the water.

### **Mycotoxins**

Fungi are plant pathogens that can cause both mycoses (infections) and mycotoxicoses (exposures to toxic fungal metabolites that may be dietary, dermal, or respiratory). Mycotoxins are ubiquitous worldwide toxic fungal metabolites and contaminants of stored cereal grains.<sup>115,116</sup> Although mycotoxins are not on the CDC threat list, individuals with chronic exposure to mycotoxins (including aflatoxin B1, ochratoxin, T-2 toxin, deoxynivalenol [DON], nivalenol [NIV], and others), often exhibit oncogenic symptoms, including liver damage, liver cancer, hemorrhaging, mental impairment, abdominal pain, vomiting, convulsions, and edema. The fact that these toxins are found naturally in commercially available cereal-based foods, including bread and related products, noodles, breakfast cereals, baby and infant foods, and rice, indicate

that a ready substrate for growth is available, and deliberate contamination of these foodstuffs may be possible. Mycotoxicoses are often undiagnosed and hence unrecognized by public health authorities, except when large numbers of people are affected.<sup>117</sup> The symptoms of mycotoxicosis depend on the type of mycotoxin; the amount and duration of exposure; the age, health, and sex of the exposed individual; and many unknown synergistic effects including genetics, dietary status, and interactions with other toxic insults.<sup>118</sup>

Large naturally occurring outbreaks of trichothecene intoxications have occurred, including a large exposure of trichothecene mycotoxin from moldy grain and bread in Orenburg, Russia, in 1944, which caused alimentary toxic aleukia and subsequent mortality in at least 10% of the population.<sup>119</sup> A 1991 outbreak caused by moldy wheat and barley affected 130,000 people in the Anhui province in China.<sup>115</sup> Fusarium mycotoxins including DON and NIV have also been discovered in corn samples in Linxian, China, in positive correlation with the incidence of esophageal cancer.<sup>119,120</sup> Although outbreaks of mycotoxicoses have decreased greatly as a result of increases in hygiene measures, they still occur

in developing countries,<sup>121</sup> are considered a serious international health problem,<sup>122</sup> and also pose a risk to domestic animals.<sup>122-126</sup>

The history of mycotoxin use as a biological weapon includes efforts by Iraq to develop and use aflatoxins during the 1980s.<sup>127,128</sup> Iraq's biological weapons program cultured strains of *Aspergillus flavus* and *A parasiticus* and extracted 2,300 liters of concentrated toxin.<sup>127,128</sup> This aflatoxin was used mostly to fill missile warheads, and the remainder was kept stockpiled.<sup>127,128</sup> The Soviet Union is suspected of deploying trichothecene toxins (NIV, DON, and T-2) in the "yellow rain" incidents in Laos and Cambodia during the 1980s. Whether the toxin exposures that occurred at that time were the result of purposeful<sup>129</sup> or natural<sup>130</sup> events has never been completely resolved. These events indicate the potential for mycotoxin use as a biological weapon or bioterrorism agent.

### Parasites

Parasites such as tapeworms (eg, *Taenia* species) may have potential for use as bioterrorism agents. It is conceivable, for example, that a culture of *Taenia solium* eggs could be poured onto a salad bar or into water, be ingested, and cause illness. Symptoms of

**TABLE 3-1**  
**PROPERTIES RELATED TO THREAT POTENTIAL OF COMMON FOOD AND WATERBORNE DISEASE PATHOGENS**

Pathogen	Incubation Period	Infective or Toxic Dose*	Mortality in United States	Bloody Diarrhea
Enterohemorrhagic <i>Escherichia coli</i>	3-4 d	10-10 <sup>2</sup>	rare	yes
<i>Salmonella typhi</i>	8-14 d	10-10 <sup>2</sup>	low	yes
<i>Salmonella</i> species	6-72 h	10 <sup>2</sup> -10 <sup>3</sup>	low	yes
<i>Shigella dysenteriae</i>	1-7 d	10-10 <sup>2</sup>	rare	yes
<i>Campylobacter jejuni</i>	2-5 d	≥ 5 × 10 <sup>2</sup>	rare	no
<i>Clostridium botulinum</i> toxin	12-72 h	70 μg <sup>†</sup>	5%-10%	no
<i>Vibrio cholera</i>	2-3 d	10 <sup>6</sup>	rare	no
<i>Cryptosporidium</i> species	7 d	9-1,024	rare	no
<i>Listeria monocytogenes</i>	3 ≥ 90 d	unknown	high	no
Hepatitis A virus	30 d	10-10 <sup>2</sup>	low	no
Norovirus	1-2 d	< 10 <sup>2</sup>	rare	no
Mycotoxins	Minutes to months <sup>‡</sup>	4 mg/kg <sup>§</sup>	rare	yes

\*The number of organisms unless otherwise noted.

<sup>†</sup>Oral lactate dehydrogenase for a 70-kg human.

<sup>‡</sup>Dose-dependent.

<sup>§</sup>Oral lactate dehydrogenase for laboratory rat.

*taeniasis* from ingestion of the eggs would include cysticercosis (parasite tissue infection), which would not appear for weeks to years following infection. However, this infection timeline should not eliminate parasites from consideration as potential bioterrorism agents; such a scenario has been proposed.<sup>131</sup> *T solium* can be transmitted person to person by food handlers with poor personal hygiene, adding to the spread of the outbreak.<sup>132</sup> Such an outbreak may go undiagnosed for an additional period, during which ill persons are seen by healthcare providers unfamiliar with tapeworm infections. A purposeful outbreak of giardiasis that occurred in Edinburgh, Scotland, in 1990 demonstrates that parasites can be used for bioterrorism. Nine individuals living in the same apartment complex developed giardiasis subsequent to the purposeful fecal contamination of an unsecured water supply.<sup>133</sup>

### Threat Potential Summary

Table 3-1 provides information about various pathogens related to their potential threat as purposeful food contaminants. Both bacterial and viral enteric pathogens were considered for this compilation. This taxonomic approach may prove useful in stimulating further discussion of pathogenicity and potential for

misuse. For example, *Salmonella* was not considered a threat agent before its use in the salad bar contamination in 1984. The prior view may have been based on factors inherent in *Salmonella* infection—a high dose of *Salmonella* is required to cause illness. If the infectious or toxic dose required for illness from an organism is the sole consideration for its classification as a bioweapon, then salmonellae should not even be considered as a threat agent. However, the use of *S typhimurium* to sicken many hundreds of people in the Dalles incident demonstrated a reality of biological agents: those that can be cultured and dispersed to cause illness will prove effective. Although no deaths occurred, the incident involved a rapid-onset illness with gastrointestinal effects that spread through 10 restaurants, causing widespread fear of food poisoning and long-lasting economic consequences in the community.<sup>134</sup> Given suitable circumstances, almost any pathogen could be used to make a target population ill. The severity of illness, including symptoms such as bloody diarrhea, also should be considered. For example, an outbreak of bloody diarrhea could have strong psychological effects upon those directly affected and perhaps lead to widespread psychological effects in the general public<sup>135</sup> if exacerbated by media coverage of the outbreak.<sup>136</sup>

## WATER SUPPLY CONCERNS

Poisoning water supplies is one of the oldest methods of biological warfare.<sup>137</sup> The earliest documented poisoned drinking water occurred in Greece in 590 BCE, when the Amphictyonic League used hellebore to poison the city of Kirrha's water source, causing the inhabitants to become violently sick and unable to move.<sup>138</sup> In current developed countries, it is more difficult for a terrorist to contaminate water because of the large volumes of water and the extensive purification processes used in modern water treatment facilities, including aeration, coagulation and flocculation, clarification, filtration, and chlorination.<sup>138</sup> All of these methods remove contaminants and pathogens in the water, whether purposefully added or not.

However, the risk to the US water supply has been known for some time. Federal Bureau of Investigation Director J Edgar Hoover noted in 1941, "It has long been recognized that among public utilities, water supply facilities offer a particularly vulnerable point of attack to the foreign agent."<sup>139</sup> A terrorist might bypass the purification process and introduce a pathogen later in the distribution system. A private well water supply system with a smaller volume of water and a less extensive purification system may be more vulnerable. Another potential avenue for deliberate waterborne

contamination is the addition of a pathogen to a building's water supply (ie, an enclosed system), with likely little or no subsequent water treatment processes and a specific target community.

Waterborne pathogens included on the CDC threat list are *V cholerae* and *C parvum*. The Milwaukee outbreak of *C parvum* demonstrates the potential of public water supply contamination to affect great numbers of people. Another example of an extensive waterborne disease outbreak resulting from contaminated well water was the 1999 *E coli* O157:H7 and *Campylobacter* outbreak involving more than 900 illnesses and 2 deaths among attendees of a New York county fair.<sup>140</sup> According to a comprehensive review of potable water threats by Burrows and Renner, potential water threat agents also include *B anthracis*, *Brucella*, *V cholera*, *C perfringens*, *Yersinia pestis*, *Chlamydia psittaci*, *Coxiella burnetii*, *Salmonella*, *Shigella*, *Francisella tularensis*, enteric viruses, smallpox virus, aflatoxin, *C botulinum* toxin, microcystins, ricin, saxitoxin, staphylococcal enterotoxins, T-2 mycotoxin, and tetradotoxin.<sup>141</sup> The 1969 hepatitis A outbreak at the College of the Holy Cross demonstrates the potential for this pathogen to cause illness when distributed in a water supply.

Communitywide outbreaks of gastroenteritis, caused by *Giardia lamblia*, *Cryptosporidium*, various *E coli* serotypes, *Torovirus*, and other infectious agents, have occurred from recreational water use, including swimming pools, water slides, and wave pools.<sup>142</sup> Nongastroenteritis recreational water outbreaks often include those caused by *Pseudomonas aeruginosa*, *Naegleria fowleri*, and *Legionella*.<sup>142</sup> A recent naturally occurring outbreak of gastroenteritis associated with a contaminated recreational water fountain at a Florida beachside park demonstrates the potential for disease transmission.<sup>143</sup> In this incident, 44% of the interviewed park visitors who used an interactive water fountain became ill. Both *C parvum* and *Shigella sonnei* were

subsequently isolated from clinical specimens obtained from these ill persons. The median age of the ill persons was 8 years. One can imagine the effect of a powerful biological agent such as *C botulinum* toxin covertly added to a recreational public water fountain in similar circumstances.<sup>144</sup>

The water utility industry and federal public health agencies have carried out plans to improve the ability to prevent as well as detect deliberate contamination of water systems.<sup>145</sup> An example of a new program to detect purposeful contamination of the water supply is the Water Sentinel program.<sup>146</sup> However, much work remains to attain full biosecurity of the US water supply.<sup>147,148</sup>

### AGRICULTURAL TERRORISM

Agricultural terrorism (agroterrorism) may be directed at stored or processed food, but some of the greatest vulnerabilities may exist close to the farm end of the farm-to-food continuum (Figure 3-1). Many of the potential bioterrorist agents are endemic, and therefore cannot easily be controlled. As with processed food and water terrorism, agroterrorism concerns are not recent developments. The historical use of biological agents to affect livestock includes the attempt to interrupt supply lines by infecting cavalry and transport animals with anthrax and glanders during World War I. In April 1915, German-American physician Anton Dilger (who had served in the German Army) returned to the United States from Germany along with cultures of *Burkholderia mallei* and *B anthracis*. His intent was to infect animals (horses and mules) that were shipped from the United States to France and England for use in cavalry and transport to support their war with Germany. Dilger propagated the bacterial cultures and tested them for virulence using guinea pigs in the basement of a house (known as "Tony's Lab") he and his brother Carl rented in Chevy Chase, Maryland, near Washington, DC.<sup>149</sup> Over the next 2 years, Dilger's bacterial cultures were used to infect horses and mules in holding pens in docks at the ports of Baltimore, Maryland; Newport News, Virginia; Norfolk, Virginia; and in New York City. Stevedores working for German steamships were recruited and provided with cork-stoppered glass vials containing the bacterial cultures, in which a hollow steel needle had been placed. The stevedores were instructed to wear rubber gloves while jabbing the animals with the needles. These cultures were also spread among the animals by pouring them directly into the animal feed and drinking water.<sup>150,151</sup>

The significance of foot and mouth disease (FMD) as a biological weapon has been known for some time, and it is perhaps the greatest agroterrorism threat for

livestock. Field trials of FMD virus dissemination were conducted in Nazi Germany's offensive biological warfare program. FMD is thought to be inherently spread through airborne virus transmission, a problematic



**Figure 3-1.** Some of the greatest vulnerabilities from agricultural terrorism may exist at the farm end of the farm-to-food continuum.

Photograph courtesy of the US Department of Agriculture, Washington, DC.



issue for outbreak containment,<sup>152</sup> and Germany considered aerial dissemination and dispersal of the FMD virus through contaminated hay and grass.<sup>153(p114)</sup>

Another attack on livestock occurred during the Mau-Mau uprising in British-controlled Kenya (1952–1960), when the Mau-Mau used the indigenous poisonous African milk bush (*Synadenium compactum*) to kill 33 cows at a mission station in 1952.<sup>154,155</sup> This use of locally obtained poisonous plants could be replicated anywhere lacking constant monitoring of animal feed.

Anticrop terrorism has also been suspected on numerous occasions. The Colorado potato beetle (*Leptinotarsa decemlineata*) is a crop pest of plants of the genus *Solanum*, which includes potatoes, tomatoes, and eggplants. During World War II, Germany initiated large-scale breeding and field trial dispersals of the insects in Germany, when Dr Martin Schwartz conducted an offensive research program at the Krufft Potato Beetle Research Station near Koblenz.<sup>153(p110)</sup> This program may have backfired by initiating local crop infestations; however, outbreaks of the pest also occurred in England and the United States, which were suspected to be caused by a German release of the insects.<sup>156,157</sup> Perhaps because of this research conducted in Nazi Germany, in 1950 Soviet-occupied East Germany accused the United States of releasing the beetle during infestation.<sup>158</sup> Herbicides have also been used for wartime missions, such as the large-scale use of the defoliant Agent Orange by the United States to both defoliate and destroy crops used by North Vietnamese forces.<sup>159</sup> In 1989 a group known as “the Breeders” announced that it had released Mediterranean fruit flies in southern California to protest the use of pesticides in that region.<sup>160</sup>

State-sponsored agricultural terrorism remains a global concern today, given vulnerabilities inherent in modern farming practices. In the United States, livestock may be susceptible to agroterrorism (Figure 3-2). Because US disease eradication efforts among livestock herds have been so successful, much of the nation’s livestock is either vaccinated or monitored for disease by farmers and veterinarians. However, the risk of harm from agroterrorism to large numbers of livestock has been increased through the widespread use of modern livestock farming, such as concentrated animal feeding operations (CAFOs). The pervasiveness of CAFOs in the US agriculture industry is all-encompassing. For example, in the US between 1997 and 2007:<sup>161</sup>

- hog factory farms added 4,600 hogs every day;
- factory farm dairies added nearly 650 cows every day;
- factory farms added 5,800 broiler chickens every hour;



**Figure 3-2.** Livestock may be more susceptible to agroterrorism than crops.

Photograph courtesy of the US Department of Agriculture, Washington, DC.

- factory farmed broiler chickens doubled to 1.1 billion;
- hog factory farms grew by 42%, to 5,144;
- the average size of egg factory farms increased by half to 614,000 hens;
- the number of cows on factory-farm dairies nearly doubled, to 4.9 million;
- the number of hogs on factory farms grew by more than a third, to 62.9 million;
- the number of factory farm egg-laying hens increased by 24%, to 266.5 million;
- the number of US beef cattle on industrial feedlots grew by 17%, to 13.5 million; and
- nearly half of factory-farm egg-laying hens were located in just five states: Iowa, Ohio, Indiana, California, and Pennsylvania.

Altogether, CAFO aggregation has had the greatest effect on livestock operations with the greatest numbers of animals. From 1982 to 1997, livestock operations with 1,000 or more animals increased by 47%. In comparison, farms with less than 25 animals (a family farm) decreased by 28%.<sup>162</sup> While such aggregation has enabled economic viability and success for the farming industry, it also can provide a single-source opportunity for foodborne contamination or adulteration for the would-be bioterrorist desiring to affect the food supply.

Upon infection, livestock may become a vector<sup>163</sup> or reservoir<sup>164</sup> for disease transmission. This potential was plainly demonstrated in the 2001 outbreak of

FMD in the United Kingdom.<sup>165</sup> This outbreak was the single largest FMD epidemic ever experienced in the world.<sup>166</sup> Agricultural and food losses to the United Kingdom exceeded \$4.6 billion,<sup>167</sup> and psychological effects in residents of the worst affected areas were extensive and long-lasting.<sup>168</sup> The United States has not had an outbreak of this disease since 1929,<sup>169</sup> and the US Department of Agriculture (USDA) has developed national protective measures to prevent a reintroduction.<sup>170</sup>

Perhaps the greatest national risks from agroterrorism involve the potential for widespread economic consequences. Not only would immediate loss to a crop occur from such an event, but incidental costs would also result from lost production, the destruction of potentially diseased products, and containment (including quarantine, drugs, and diagnostic and veterinary services). The costs of these programs would be borne by farmers as well as federal and state governments.<sup>171</sup> Export markets would be rapidly lost as other nations close their borders to imports from a country

with diseased livestock. As an example, a single case of mad cow disease (bovine spongiform encephalopathy) was found in Washington state on December 23, 2003; by December 26, Japan had banned all US beef imports, and beef prices dropped by as much as 20% in the following week.<sup>172</sup> Additionally, multiplier economic effects would occur from decreased sales by agriculturally dependent businesses and tourism. Other animal pathogens besides FMD and bovine spongiform encephalopathy that could have severe economic consequences if uncontrolled include highly pathogenic avian influenza,<sup>173</sup> rinderpest,<sup>174</sup> and African<sup>175</sup> and classical swine fever.<sup>176</sup>

The USDA's Animal and Plant Health Inspection Service has developed a select agent and toxin list of pathogens and toxins that endanger agriculture in the United States<sup>177</sup> (some of these zoonotic pathogens also endanger humans and appear on the CDC Category A list<sup>4</sup>; these pathogens are listed separately by the USDA as overlap agents and toxins). Another USDA list enumerates harmful plant pathogens.<sup>177</sup>

## SMUGGLING AND INVASIVE SPECIES

The problem of smuggling and the unintentional introduction of invasive species has grown in recent years. Increased and more rapid international trade, increased trade in fresh commodities, new travel and trading routes, and increased difficulties in enforcing quarantines have all contributed to this problem. The potential consequences of smuggling and unintentional introduction of invasive species may go far beyond the direct damages or costs of control. The economic costs of all invasive species in the United States is estimated at between \$120 billion and \$138 billion per year.<sup>178,179</sup> These invasive species consist of microbes (30.1%), mammals (27.2%), plants (25.0%), and arthropods (15.4%). The full range of

economic costs of biological species invasions reaches far beyond the immediate impacts on the affected producers and often include consequences to local, national and global markets. In 1995, member nations of the World Trade Organization signed the Uruguay Round Agreement on the Application of Sanitary and Phytosanitary Measures, which set out basic rules for food safety and animal and plant health standards and increased the transparency of sanitary and phytosanitary measures.<sup>180</sup> The agreement covers all measures to protect human or animal health from foodborne risks, human health from animal- or plant-carried diseases, and animals and plants from pests or diseases.<sup>180</sup>

## FOOD AND WATER SECURITY

On December 3, 2004, the former secretary of the Department of Health and Human Services, Tommy Thompson, warned of a possible terrorist attack on the nation's food supply: "For the life of me, I cannot understand why the terrorists have not attacked our food supply, because it is so easy to do . . . We are importing a lot of food from the Middle East, and it would be easy to tamper with that."<sup>182</sup> In American society, the farm-to-food continuum, which includes production, processing, distribution, and preparation, has myriad potential vulnerabilities for natural and intentional contamination.<sup>182</sup> Centralized food production and widened product distribution systems

present increased opportunities for the intentional contamination of food.<sup>183</sup> As covered in the discussions above, many opportunities exist along the food and water production continuum to accidentally or intentionally introduce various pathogens, many of which are not categorized as threat agents.<sup>184</sup> Strategies to counter these threats should focus on enhancing knowledge of all raw material inputs to the system; identifying and addressing the most likely points of vulnerability; disposing of end products after they leave the systems; and accounting for employees, visitors, computers, and physical security throughout the continuum.

Knowledge of the various processes involved in food production will help to determine potential vulnerabilities for agricultural terrorism. The typical food distribution system includes agricultural production and harvesting, storage and transport of raw commodities, processing and manufacture, storage and transport of processed and manufactured products, wholesale and retail distribution, and the food service sector.<sup>185</sup> The responsibility for food safety and security throughout the food distribution network is shared by the producers and suppliers as well as many different state and federal agencies. Typically, a state's health and agricultural agencies ensure that the food comes from safe sources and is served with safeguards to prevent foodborne disease transmission. Equivalent federal agencies share these responsibilities, including the US Food and Drug Administration, USDA, Department of Health and Human Services, US Public Health Service, CDC, and other partner agencies now part of the Department of Homeland Security, including the Federal Bureau of Investigation and the US Customs Service.

One prevention strategy is to anticipate intentions or motivations that could result in an attack using a particular product or organization. These motivations could include religion or ideology; personal grievances (real or perceived); and contentious issues such as animal rights, environmental protection, and abortion. Research facilities, food processors, and food retailers could be targets of terrorism and should take extra preventive measures. Knowledge of terrorism trends can be an indicator for the need to change security measures to meet the threat. However, because the US food industry is highly competitive on a price basis, additional preventive measures may only be an option if they are government subsidized.

From an attacker's standpoint, the choice of methods and weapons is determined by the target and the delivery medium. It is rare that someone would attempt to cause harm without consideration of whom or how many people are affected. The target population may then define the vulnerabilities. For example, animal feed could be contaminated if the goal was to affect a CAFO.

Strategies also can be implemented to address specific vulnerabilities. The first task is to define production processes in terms of the inputs and outputs at all potential nodes of vulnerability. For example, foods that are either eaten uncooked or that can be contaminated after cooking should receive special quality control attention. Also, knowledge of where raw materials including water are obtained can help identify needs for enhanced security and accountability.

A thorough knowledge of the existing hazard analysis critical control points (HACCPs) for each food item considered to be a potential vehicle for foodborne disease is essential to understanding and preventing illness. A comprehensive HACCP analysis will provide a systematic method of documenting that food safety hazards have been addressed.<sup>186</sup> Hazard analysis involves food safety issues only, including storage and holding temperatures, pH, sanitary conditions, physical storage security, and any other factor that could impact the safety and integrity of a food item during manufacture, storage, delivery, or food preparation.<sup>186</sup> General guidance to conducting an HACCP program would necessarily include:<sup>186</sup>

- Hazard analysis: what are the food safety hazards that can be controlled?
- Establish critical control points (CCP): where can things go wrong, and how can they be controlled?
- Establish critical limits: what physical values (temperature, pH, etc) indicate that the process is in control?
- Establish monitoring procedures: how will the CCPs be monitored?
- Establish corrective actions: what happens if a critical limit is exceeded?
- Establish a record keeping system: "If it isn't written down, it didn't occur."
- Establish verification procedures: how can you know if the system works?

HACCP principles have been successfully applied to the production, storage, and serving of many types of food items.<sup>187-189</sup> However, there remain many challenges to providing a safe and wholesome food supply, and resolution of issues through the use of HACCP may also provide solutions that could prevent bioterrorism. For example, food items that are common sources of foodborne infections may also present opportunities to a potential bioterrorist, by virtue of a lack of proper temperature use and monitoring. It has been demonstrated that salsa and guacamole are frequent vehicles of foodborne disease outbreaks in the United States.<sup>190</sup> Unsurprisingly, fresh serrano and jalapeno peppers used in these food items have caused huge multistate *Salmonella* outbreaks.<sup>191,192</sup> Fresh salsa and guacamole require careful preparation and storage, and food prevention strategies based upon the HACCP principles can greatly help to reduce the incidence of foodborne disease, as well as to maintain monitoring of these food items.

Focus is often targeted on the inputs to food, water, or agricultural production, and when a product leaves the plant, that attention may be dis-

continued. The time and route of delivery, as well as the security of the transportation, may be the most vulnerable points in the continuum and should not be overlooked when planning security. Studying incidents of nonpurposeful foodborne pathogen contamination, such as the 1985 Minnesota salmonellosis outbreak,<sup>193</sup> may reveal potential avenues for purposeful outbreak scenarios. This outbreak and many others demonstrate that foodborne bioterrorism might have greater chances of success when pathogens are introduced after processing and as close to consumption as possible, thus circumventing opportunities for dilution and destruction by cooking or pasteurization.

Implementing rational employee hiring and accountability procedures may also effectively mitigate food, water, or agricultural vulnerabilities.<sup>186</sup> Additional strategies include implementing procedures for laboratory testing and monitoring, reporting and investigating inspection discrepancies, and ensuring computer and information security.<sup>186</sup>

Various disease surveillance systems (covered in greater details in other chapters) are in place, including

local, state health agency, and CDC programs to track and identify trends in foodborne illness, including FoodNet,<sup>194</sup> PulseNet,<sup>195</sup> CalciNet,<sup>196</sup> WBDOS,<sup>197,198</sup> and syndromic surveillance systems such as RODS<sup>199</sup> and BioSense.<sup>200</sup> Additional methods to inspect and protect food and water supply chains, and rapidly integrate disease surveillance, are being actively examined and implemented.<sup>201</sup>

Furthermore, under the Food Safety and Modernization Act of 2010 the Food and Drug Administration has proposed a rule that would require the largest food businesses in the United States and overseas to take measures to prevent food facilities from being targeted by intentional attempts to contaminate the food supply.<sup>202</sup> Under the proposed rule, food facilities would be required to have a written food defense plan addressing significant vulnerabilities in their food production process, and to take measures to address these vulnerabilities, establish monitoring measures and corrective actions, confirm that the system is working, and ensure that workers assigned to vulnerable areas receive suitable training and maintain records.<sup>202</sup>

## SUMMARY

Any biological pathogen, whether bacteria, virus, toxin, or parasite, has the potential to be used in a terrorism context. Historical examination of both purposeful and inadvertent food and waterborne disease outbreaks can greatly assist in understanding how such events occur and how they may be prevented. A comprehensive understanding of animal produc-

tion and crop farming, as well as food production and distribution, is required to ensure protection for the agricultural industry from terrorism events. Absolute safety of the food supply is perhaps an unattainable goal, but should be the benchmark for which all food protection and agricultural efforts are directed.

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