WATER AND BIOTERRORISM: Preparing for the Potential Threat to U.S. Water Supplies and Public Health

Patricia L. Meinhardt
Center for Occupational and Environmental Medicine, Arnot Ogden Medical Center, Elmira, New York 14905; email: pmeinhardt@aomc.org

Key Words water terrorism, waterborne disease, intentional water contamination, biowarfare agents, biotoxins

Abstract Water supplies and water distribution systems represent potential targets for terrorist activity in the United States because of the critical need for water in every sector of our industrialized society. Even short-term disruption of water service can significantly impact a community, and intentional contamination of a municipal water system as part of a terrorist attack could lead to serious medical, public health, and economic consequences. Most practicing physicians and public health professionals in the United States have received limited training in the recognition and evaluation of waterborne disease from either natural or intentional contamination of water. Therefore, they are poorly prepared to detect water-related disease resulting from intentional contamination and may not be adequately trained to respond appropriately to a terrorist assault on water. The purpose of this review is to address this critical information gap and present relevant epidemiologic and clinical information for public health and medical practitioners who may be faced with addressing the recognition, management, and prevention of water terrorism in their communities.

INTRODUCTION

Recent terrorist activity in the United States has forced the public health community, federal regulatory agencies, and local water utilities to consider the possibility of intentional contamination of U.S. water supplies as part of an organized effort to disrupt and damage important elements of our national infrastructure (19, 39, 59). Water supplies and water distribution systems represent potential targets for terrorist activity in the United States because of the essential role that water plays in every segment of our industrialized society (39). Even short-term disruption of the provision of water can have a significant impact on a community, and intentional contamination of a municipal water system as part of a terrorist attack could lead to sobering medical, public health, and economic consequences. In the past, protection of potable water supplies from intentional contamination with biological
agents and biotoxins was a concern primarily of the military, which was tasked with protecting troops from bioweapons exposure in the field (9, 42, 62). Since September 11, 2001, there is growing concern that biological warfare agents may be used against the U.S. civilian population, with water as one possible vehicle of transmission or mode of dispersal of weaponized compounds (19, 21, 35, 39, 59).

The plausibility of intentional contamination of water supplies as part of an overt or covert terrorist act has been reinforced by recent congressional testimony, a consensus statement by a governmental review panel, and a joint Centers for Disease Control and Prevention (CDC) and Environmental Protection Agency (EPA) water advisory health alert (15, 47). As part of their 2002 congressional report, the National Research Council of the National Academy of Sciences concluded that water supply system contamination and disruption should be considered a possible terrorist threat in the United States (47). On February 7, 2003, the National Terrorism Threat Level was increased to a “high risk” threat level on the basis of information received and analyzed by the federal intelligence community. Subsequent to this heightened alert, the CDC and the EPA issued a Water Advisory in Response to the High Threat Level describing the need for enhanced vigilance by the public health and water utility community regarding the risk of a terrorist attack on the nation’s water infrastructure (15) (Figure 1). Apprehension regarding a terrorist assault on drinking water systems has also been reinforced by news reports and recent arrests of suspects charged with threatening to contaminate municipal water supplies in the United States (46, 59). In addition, President George Bush noted in his 2002 State of the Union Address (49) that captured Al Qaeda documents included detailed maps of several U.S. municipal public drinking water systems.

A review of two recent examples of waterborne disease outbreaks resulting from accidental contamination of municipal drinking water systems illustrates the potential consequences of an intentional act of water terrorism (45). The massive outbreak of waterborne cryptosporidiosis in Milwaukee, Wisconsin, in 1993 is an example of how contaminated water distributed through a municipal water system can result in significant medical, public health, and economic consequences in a community. An estimated 403,000 Milwaukee residents developed diarrhea, which reflected an attack rate of 52% of the population served by the affected municipal water system. In addition, more than 4000 Milwaukee residents were hospitalized during the waterborne outbreak, and cryptosporidiosis was listed as the underlying or contributory cause of death in 54 residents following the outbreak. Investigators estimate that 725,000 productive days were lost as a result of the water contamination event, at a cost in excess of $54 million in lost work time or additional expenses to residents and local authorities in Milwaukee. In 2000, the municipal water supply of Walkerton, Ontario, was contaminated with E. coli O157:H7, resulting in 2300 symptomatic residents and 7 deaths attributed to the waterborne disease outbreak. More than $11 million was required to reconstruct the community municipal water system and install temporary filtration after the contamination event. Current estimates of the total cost of the Walkerton,
Figure 1  CDC and EPA Water Advisory in Response to High Threat Level distributed as part of the emergency notification Health Alert Network (HAN) on February 7, 2003 (15).
Ontario, waterborne disease outbreak and municipal water contamination event have reached $155 million.

Both overt and covert acts of terrorism involving weaponized biological pathogens and biotoxins pose an intimidating public health threat and a significant challenge to our healthcare infrastructure, as was demonstrated following the intentional release of *Bacillus anthracis* spores through the U.S. postal system in 2001 (31). Most public health and law enforcement authorities consider a successful attack using weaponized biological agents in the United States as “simply a matter of time” (30). Although significant progress has been made to improve the terrorism preparedness of the medical and public health community in the United States, most healthcare providers and public health professionals have a limited working knowledge of the skills necessary to recognize and manage waterborne biological agents that terrorists may use to threaten the U.S. civilian population (46). Therefore, the purpose of this review is to summarize relevant epidemiologic and clinical information and highlight valuable diagnostic and management tools for public health and medical practitioners who may be faced with addressing the recognition, management, and prevention of acts of water terrorism in their communities.

THE PUBLIC HEALTH CHALLENGE OF WATER TERRORISM

Although public health and medical practitioners may not be able to prevent the first cases of illness or injury resulting from a bioterrorism attack, they are positioned to play a critical role in minimizing the impact of such an event by practicing public health with an increased index of suspicion that such an attack may occur in their communities (7, 30). Even if the probability of occurrence remains low, the public health consequences of a successful overt or covert terrorist attack with biological agents would be serious (37). With prompt diagnosis and proper management including preventive and therapeutic measures, prepared medical and public health professionals may make the difference between a controlled response to a terrorist incident and a public health crisis (33).

Therefore, early detection and rapid response to biological terrorist assaults on the nation’s infrastructure, including U.S. water supplies, are critical elements to any effective terrorism response strategy. This is particularly important when addressing the possibility of intentional water contamination resulting from bioterrorism. In a water terrorism scenario, early detection will be critical to diminish (a) the public health impact of the contamination event, (b) the secondary disruption to potable water distribution and availability, and (c) the psychological impact of the public’s lack of confidence in water safety and quality following a water terrorism event (39, 46).

Recognizing and managing a waterborne disease outbreak and the health effects of exposure to water contamination are diagnostic challenges in the best of
circumstances. These challenges would be even more significant in an emergency situation resulting from waterborne exposure to potentially weaponized biological agents (46). The public health and medical challenges associated with waterborne disease resulting from an act of water terrorism include but are not limited to the following.

1. Prompt identification of waterborne disease resulting from water terrorism may be confounded by difficulties in early diagnosis. Many diseases resulting from exposure to weaponized biological agents present with vague, nonspecific symptoms in the early phase of illness and may be difficult to differentiate from naturally occurring disease in a community (23). In addition, the signs and symptoms of waterborne disease and the health effects of water contamination are often nonspecific and mimic more common medical conditions and disorders unrelated to water contaminant exposure (45).

2. Many weaponized biological agents display a significantly different clinical picture when the route of exposure is ingestion. Using food and water as a mode of dispersion for weaponized biological agents (7, 23) may confound diagnosis, delay treatment, and impede protective public health measures if epidemiologic investigations and clinical assessments are restricted to evaluation of inhalation and cutaneous routes of exposure alone (9, 28, 30).

3. A bioterrorist attack on water supply systems may not first occur in a populous community usually considered as a preferred target. A small outbreak of terrorism-related waterborne disease may act as a warning of a more large-scale attack. Water systems in small rural communities may represent testing grounds for larger-scale attacks in metropolitan municipal water systems (46). This potential scenario reinforces the need for incorporation of possible terrorism-related waterborne disease into the daily differential diagnosis of every public health and medical practitioner in practice in the United States, no matter how small or large the community (51, 58).

4. Medical and public health practitioners will play a critical role as front-line responders in detecting water-related disease resulting from biological terrorism. Although environmental detection and water-quality testing methods for recognizing intentional contamination of water are improving (59), the most likely initial indication that a water contamination event has occurred in a community will be a change in disease trends and illness patterns. Early recognition, timely outbreak investigations, accurate diagnosis, and conscientious reporting by the medical and public health community of suspected waterborne terrorism disease cases will be essential to maintaining water security and safety (46).

5. Water-related disease resulting from intentional contamination with biological agents may present as benign symptoms or self-limited illness in a healthy patient population, whereas the same waterborne exposure in a vulnerable patient population may result in significant morbidity and mortality. The
impact of a terrorist attack depends on not only the type of agent used or method and efficiency of dispersal but also on the type of population exposed and their level of immunity or vulnerability (9, 36). Individual vulnerability to weaponized biological compounds including waterborne agents may vary widely, and differences in host susceptibility factors may complicate recognition of an intentional water contamination event.

6. A coordinated and effective response to acts of water terrorism will depend on cooperation among a multidisciplinary team of professionals. As in the case of any type of antiterrorism preparedness (38, 55), a coordinated and effective response to mitigate the negative consequences of an intentional act of water terrorism will depend on cooperation among a multidisciplinary team of health care providers, public health and water utility practitioners, law enforcement professionals, and community leaders. The medical and public health community will need to develop and foster new partnerships and working relationships with water utility practitioners to protect the public’s health and ensure water safety (46).

7. Medical and public health practitioners will be faced with providing credible and timely risk communication and public notification of a suspected water contamination event. As a result of heightened public awareness regarding the potential for additional terrorist activity, the medical and public health community will be required to play a leading role in risk communication with the public, if an act of waterborne terrorism occurs in the United States. Health care providers are among the most trusted sources of information for the general public regarding drinking water quality and safety in the United States (45), and community residents will immediately turn to their health care providers and public health leaders for advice regarding the safety of their drinking water during and after an intentional water contamination event.

Effective risk communication by the medical and public health community will play a critical role in a coordinated response to intentional acts of water terrorism and will be essential to prevent panic and hysteria in the community experiencing the terrorism event (7, 46). Risk communication will be challenging since there will be pressure from the public and media to provide information before confirmatory evidence is available. Incorporating the public and media as key partners in risk communication efforts during and after a terrorism event can help modulate the ultimate impact on a community. Health care providers will need to embrace the concept that providing timely information and effective risk communication may be as important as providing medical care in the event of a water terrorism attack (46).

Any effective response to the public health threat of water terrorism must include targeted education and terrorism preparedness training for the medical and public health community (46). Critical elements of any antiterrorism preparedness training for public health and medical practitioners include prompt recognition,
treatment, and prevention of the public health consequences of weaponized biological agent exposure in a community population (5, 38). However, public health officials and health care providers must become familiar with not only the clinical presentation, diagnosis, management, and prevention of terrorism-related disease but also the appropriate mechanisms for communicating with law enforcement agencies, public utilities, the media, and the concerned public (1, 60).

A thorough understanding of the recognition and management of waterborne disease resulting from intentional contamination of U.S. water supplies and distribution systems will be essential for several reasons if an effective response to acts of water terrorism is to be implemented by the public health and medical community. The illness and injury resulting from community exposure to weaponized biological agents would not be part of any health care provider or public health practitioner’s routine clinical or public health practice experience (38, 53, 57). Most practicing physicians and public health professionals in the United States have received limited training in the recognition and evaluation of waterborne disease from either natural or intentional contamination of water. Therefore, they are poorly prepared to detect water-related disease resulting from intentional contamination and may not be adequately trained to respond appropriately to a terrorist assault on water (45, 46). The remainder of this review attempts to address this critical information gap and presents relevant epidemiologic and clinical information for public health and medical practitioners who may be faced with addressing the recognition, management, and prevention of water terrorism in their communities.

WATER AS A DISPERSAL MECHANISM FOR BIOTERRORISM

The deliberate contamination of the wells, reservoirs, and other water sources of civilian populations has been employed as a method of attack by opposing military forces throughout the history of war (18). Many armies have resorted to using this method of biowarfare, including the Romans who contaminated the drinking water of their enemies with diseased cadavers and animal carcasses (18, 65). With enhanced technology and modern scientific advances, the mechanisms of biowarfare agent dispersal have expanded considerably.

In addition, terrorist attacks on the U.S. population with deliberate release of biological warfare agents may be difficult to identify quickly and reliably in the environment (65). Intentional contamination of water with a biological pathogen or biotoxin that is colorless, odorless, tasteless, and therefore not detectable by human senses presents a serious challenge for those responsible for environmental detection of such a biological compound in water (21, 23).

As part of a collaborative effort, water utilities and several federal public health agencies have undertaken a major effort to improve and enhance their ability to detect and characterize deliberate contamination of water systems in the United States (24–27, 59). As a result, U.S. water systems are currently more physically
secure with multiple layers of enhanced protection. However, there remain several potential points in the U.S. water supply and distribution systems that could be vulnerable to intentional contamination. In their congressional report addressing infrastructure vulnerability to acts of terrorism, the National Research Council of the National Academy of Sciences outlined a series of these potential points of contamination in the U.S. water supply (47). Other public health and water utility specialists have also addressed this issue and presented other possible points of intentional contamination. This information is summarized in Table 1 and can be a resource for health care providers and public health professionals to use when evaluating an unusual symptoms complex or an atypical illness pattern, which may represent a case of waterborne terrorism (20, 21, 23, 39, 47, 48, 61).

### TABLE I
Possible points of contamination of U.S. water from acts of water terrorism\(^a\),\(^b\)

<table>
<thead>
<tr>
<th>Potential Point</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream of a community water supply system or collection point</td>
<td>Water supply systems are composed of small streams and bodies of water, rivers, service reservoirs, aquifers, wells, and dams that may act as points of deliberate contamination of water.</td>
</tr>
<tr>
<td>Community water supply intake access point or at the water treatment plant</td>
<td>Many water supply systems are designed to receive water from source water reserves at a central intake point; this source water is subsequently filtered and sanitized at the community water treatment facility for eventual distribution as potable water. Both water-intake points and community water treatment plants may be targeted for terrorist activity and deliberate water contamination.</td>
</tr>
<tr>
<td>Selected points in the posttreatment water distribution system</td>
<td>Treated water is distributed to water consumers or end-users through transmission pipelines to homes and businesses. Selected portions of a water distribution system or water main are also potential points of water contamination that may be targeted by terrorists and could affect a subdivision, specific neighborhood, school, medical center, or nursing home.</td>
</tr>
<tr>
<td>Private home or office building water supply connection, individual building water supply, water tanks, cisterns, or storage tanks</td>
<td>Treated water stored very close to the water consumer or end-user as well as individual house or building connections may serve as points of water contamination by terrorists.</td>
</tr>
<tr>
<td>Water used in food processing, bottled water production, or commercial water</td>
<td>Water used for food processing or preparation as well as bottled water production also represent points of potential water contamination by terrorists.</td>
</tr>
<tr>
<td>Deliberate contamination of recreational waters and receiving waters</td>
<td>Both treated and untreated recreational waters may serve as points of potential contamination of water, including swimming pools, water parks, and natural bodies of water (small lakes and ponds). Receiving waters such as rivers, estuaries, and lakes may be secondarily contaminated with wastewater from sanitary and storm sewer systems that may have been environmentally contaminated by biological warfare agents.</td>
</tr>
</tbody>
</table>

\(^a\)A number of the potential points of contamination of water outlined above are more probable terrorist targets than others (19, 47). However, all health care providers and public health practitioners should consider these potential sources of water contamination and unusual modes of delivery of biowarfare agents when evaluating a suspected case of terrorism-related disease (20, 21, 23, 39, 47, 48, 61).

\(^b\)Modified and reprinted with permission from the author and Arnot Ogden Medical Center (46).
WATER AND BIOTERRORISM

DISSEMINATION OF BIOWARFARE AGENTS THROUGH MULTIPLE MODES OF DISPERsal INCLUDING WATER

Possible Water-Related Exposure Scenarios

Following the release of a biological warfare compound, the nature and extent of the medical and public health consequences resulting from the intentional exposure depend on a multitude of factors (66):

- the method by which the biowarfare agent is dispersed,
- the biowarfare agent characteristics profile including toxicity and virulence,
- the amount of biowarfare compound released and level of infective dose,
- the state of the exposed individual’s host susceptibility and level of personal protection,
- the routes of exposure used to disperse the biowarfare agent, and
- the movement and dilution of the biowarfare agent in the environment.

Public health practitioners and healthcare providers faced with evaluating a suspected case of terrorism-related disease will rarely have access to the type of extensive exposure information detailed above when completing an epidemiologic investigation or when questioning exposed patients, most of whom may be unaware of biowarfare agent contact prior to presentation of their symptoms. Therefore, public health and medical practitioners, particularly communicable disease control epidemiologists and other surveillance experts, must become familiar with the various modes of dispersal or methods of dissemination that may be utilized to disperse biological warfare agents to effectively recognize cases of terrorism-related exposure and prevent additional cases from occurring in their community. Several important exposure scenarios should be noted during an outbreak investigation or during a clinician’s evaluation of a suspicious case of intentional exposure to biological agents that may include water as one exposure pathway.

1. Intentional contamination of water may occur with nonweaponized, naturally occurring agents. In many cases, terrorism-related disease produced by biowarfare agents mimics naturally occurring disease because the illness may be caused by the same pathogen found in nature (23). Naturally occurring waterborne diseases can cause significant morbidity and mortality in a community as well (1, 2, 6, 12, 14, 22, 50). Therefore, intentional contamination of water supplies with nonweaponized, naturally occurring pathogens or contaminants should also be considered a credible exposure source when completing an exposure history of a suspicious case of terrorism-related disease.

2. Patients may present with a different clinical picture when the route of exposure is ingestion rather than inhalation or dermal absorption. Using food and water supplies as a mode of dispersal for biological warfare (7, 23)
may confound diagnosis, delay treatment, and impede protective public health measures if exposure histories are restricted exclusively to questions regarding inhalation and cutaneous routes of exposure (9, 28). Many biological warfare agents display a significantly different clinical picture when the route of exposure is ingestion rather than inhalation or cutaneous absorption, and this unusual exposure pathway must not be overlooked by public health or medical practitioners.

3. Patients may be exposed to multiple biowarfare agents and coinfections may be common. A terrorist attack on the U.S. population may take place with multiple biological agents, resulting in exposed patients presenting with both acute and delayed symptoms and short- and long-term medical sequelae from mixed biological agent exposure (23, 52). Multiple biowarfare agent exposures could lead to the presence of coinfections and confusing syndromes associated with different biological pathogens and biotoxins. Coinfections with multiple waterborne pathogens is a typical scenario during waterborne outbreaks resulting from natural or accidental water contamination (45). Therefore, when evaluating a suspected case of terrorism-related disease, the exposure history and differential diagnosis must include the possibility of multiple warfare agent exposures and coinfections (46).

4. Water may act as an exposure pathway from both direct contamination as well as environmental contamination from secondary sources. Waterborne exposure to biological warfare agents may result from deliberate direct contamination of water supplies, recreational waters, and receiving waters. However, water may also become indirectly contaminated by biowarfare agents through environmental contamination of wastewater from such sources as sanitary and storm sewer systems receiving the run-off from an aerosolized terrorist attack. In addition, patient decontamination procedures that include flushing contaminated skin surface with water may generate decontamination wastewater and indirect contamination of water systems after a terrorist event (43, 46).

Intentional Dispersal of Bioweapons Using Multiple Exposure Pathways or Portals of Entry

Biological warfare may include the use of unusual biological agents as weapons delivered through unconventional mechanisms of dispersal via unexpected exposure pathways (23, 46, 66). The diversity of dispersal mechanisms for weaponized biological agent release is extensive, ranging from deliberate release of pathogens that may contaminate food supplies or infect livestock to intentional contamination of community water systems in a targeted population (66). The various modes of delivery of biowarfare agents include aerosols or aerial sprays, foodborne and waterborne vehicles, vectorborne and dermal delivery, and intentional injection (23, 61).
Biowarfare agents may enter the body through portals of entry of naturally occurring disease or through biotoxin exposure. Appropriate terrorism preparedness skills for the public health and medical community must include familiarity with the various routes of exposure of biological warfare agents to prevent a missed diagnosis and complete an effective outbreak investigation in the event of a bioterrorist attack. To protect the public’s health, working knowledge of the multiple routes of biowarfare agent exposure is essential (23, 61, 66). Possible routes include

1. the natural reservoirs of the biological pathogen or biotoxin,
2. the potential vehicles of transmission of the biological pathogen or biotoxin, and
3. the possible biological warfare or weaponized modes of delivery of the biological pathogen or biotoxin.

Many difficult diagnostic challenges are inherent, for even the most experienced medical or public health practitioner, in evaluating a suspicious case of waterborne terrorism (46). A key factor in the accurate diagnosis and appropriate management of waterborne disease resulting from water terrorism is inclusion of water by medical and public health practitioners as one possible exposure pathway of biowarfare agents at the time of initial case presentation. The biological agents and biotoxins that have been designated as potential bioterrorist weapons arise from varied biological compounds and can be dispersed through multiple exposure pathways including water (7, 23, 28, 30, 35, 39, 42, 44).

A summary of selected biological pathogens and biotoxins that have been designated as possible biowarfare agents of public health concern is presented in Table 2 for reference and includes the natural reservoirs, potential vehicles of transmission, and possible warfare modes of delivery for each biological agent. The waterborne route of exposure to these potential biowarfare agents has been placed in context with other exposure pathways of clinical and public health significance when terrorist activity is suspected. The selected biological pathogens and biotoxins presented in Table 2 have been identified by multiple governmental, military, and medical organizations as possible biowarfare agents that pose a direct threat to public health.

**CLINICAL APPROACH TO DIAGNOSING WATERBORNE BIOWARFARE AGENT EXPOSURE AND DISEASE**

**Clinical Challenges of Evaluating Waterborne Biowarfare Agent Exposure and Disease**

Early recognition of unusual illness patterns and rare diseases resulting from intentional dispersal of weaponized biological pathogens and biotoxins is a serious challenge facing every health care provider and public health practitioner in the United States. The medical and public health consequences of this difficult
**TABLE 2**  
Selected biological agents and biotoxins of public health concern that include water as a potential mode of dispersal\(^a\)\(^b\)

<table>
<thead>
<tr>
<th>Etiologic agent</th>
<th>Natural reservoirs</th>
<th>Potential vehicles of transmission</th>
<th>Possible biological warfare modes of delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthrax</strong></td>
<td>Soil with worldwide distribution</td>
<td>Airborne, foodborne, vectorborne, cutaneous contact with infected tissue</td>
<td>Aerosolized spores during a biowarfare attack, food contamination, and direct or incidental water contamination</td>
</tr>
<tr>
<td><em>Bacillus anthracis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brucellosis</strong></td>
<td>Cattle, swine, goats, sheep, camels, dogs, coyotes</td>
<td>Airborne, foodborne, entry through cutaneous or mucosal abrasion</td>
<td>Aerosolized release during a biowarfare attack, possible food and water contamination</td>
</tr>
</tbody>
</table>
| *Brucella melitensis*,  
*Brucella suis*,  
*Brucella abortus*,  
*Brucella canis* (undulant or Malta fever) |                                                         |                                                                         |                                                                                      |
| **Cholera**         | Aquatic environments worldwide                        | Waterborne, foodborne, wound infections from exposure to contaminated water | Intentional contamination of potable water and food                                   |
| *Vibrio cholerae*   |                                                         |                                                                         |                                                                                      |
| **Clostridium perfringens** | Soil, gastrointestinal tract of healthy humans and animals | Foodborne, waterborne                                                | Possible aerosolized release during a biowarfare attack, intentional contamination of food or water |
| **Glanders**        | Horses, mules, donkeys                                 | Airborne, entry through abraded or lacerated skin, ingestion           | Possible aerosolized release, possible water contamination                             |
| *Burkholderia mallei* (formerly *Pseudomonas mallei*) |                                                         |                                                                         |                                                                                      |
| **Melioidosis**     | Soil and water throughout the world                    | Inoculation of skin lesion from contact with contaminated soil or water, aspiration or ingestion of contaminated water, inhalation of contaminated dust | Presumably aerosolized release during a biowarfare attack                              |
| *Burkholderia pseudomallei* (formerly *Pseudomonas pseudomallei*) |                                                         |                                                                         |                                                                                      |
### Parasitic pathogens

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Hosts</th>
<th>Mode of Transmission</th>
<th>Potential Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidiosis</td>
<td>Humans, diverse range of animals including cattle and other domestic animals</td>
<td>Foodborne, waterborne, person-to-person and animal-to-person transmission, possibly airborne</td>
<td>Contamination of potable water supplies</td>
</tr>
<tr>
<td>Cryptosporidium parvum and other Cryptosporidium sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Viral pathogens

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Hosts</th>
<th>Mode of Transmission</th>
<th>Potential Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatitis A virus (HAV)</td>
<td>Humans, rarely other nonhuman primates</td>
<td>Person-to-person transmission, waterborne, foodborne</td>
<td>Possible intentional contamination of potable water supplies</td>
</tr>
<tr>
<td>Smallpox Variola major</td>
<td>Humans (eradicated), only in designated laboratories officially</td>
<td>Person-to-person, airborne, direct contact with skin lesions or contaminated objects</td>
<td>Dissemination through aerosol cloud or contaminated items, possible water threat</td>
</tr>
</tbody>
</table>

(Continued)
### TABLE 2  (Continued)

<table>
<thead>
<tr>
<th>Viral pathogens</th>
<th>Etiologic agent</th>
<th>Natural reservoirs</th>
<th>Potential vehicles of transmission</th>
<th>Possible biological warfare modes of delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Viral Encephalitides</td>
<td>Rodents, mosquitoes, horses as amplifying hosts</td>
<td>Arthropodborne</td>
<td>Weaponized aerosolized form</td>
</tr>
<tr>
<td></td>
<td>Viral Hemorrhagic Fevers</td>
<td>Rodents, mosquitoes, ticks, primates, humans</td>
<td>Arthropodborne, aerosol or fomites from slaughtering infected animals</td>
<td>Delivery by aerosol release</td>
</tr>
<tr>
<td></td>
<td>Psittacosis</td>
<td>Birds, poultry</td>
<td>Inhalation of infected droppings and secretions</td>
<td>Presumably aerosolized release, possible water treat</td>
</tr>
<tr>
<td></td>
<td>Q Fever</td>
<td>Sheep, goats, cattle, dogs, cats, some wild animals, ticks, birds</td>
<td>Airborne, inhalation of dust from infected tissue, direct contact with infected animals</td>
<td>Aerosolized form, contamination of food, possible water threat</td>
</tr>
<tr>
<td></td>
<td>Typhus</td>
<td>Humans</td>
<td>Louse-borne</td>
<td>Aerosol dissemination</td>
</tr>
</tbody>
</table>

### Rickettsial and Rickettsial-like Pathogens

<table>
<thead>
<tr>
<th>Rickettsial and Rickettsial-like Pathogens</th>
<th>Etiologic agent</th>
<th>Natural reservoirs</th>
<th>Potential vehicles of transmission</th>
<th>Possible biological warfare modes of delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psittacosis</td>
<td>Chlamydia psittaci</td>
<td>Birds, poultry</td>
<td>Inhalation of infected droppings and secretions</td>
<td>Presumably aerosolized release, possible water treat</td>
</tr>
<tr>
<td>Q Fever</td>
<td>Coxiella burnetti</td>
<td>Sheep, goats, cattle, dogs, cats, some wild animals, ticks, birds</td>
<td>Airborne, inhalation of dust from infected tissue, direct contact with infected animals</td>
<td>Aerosolized form, contamination of food, possible water threat</td>
</tr>
<tr>
<td>Typhus</td>
<td>Rickettsia prowazekii</td>
<td>Humans</td>
<td>Louse-borne</td>
<td>Aerosol dissemination</td>
</tr>
</tbody>
</table>

### Bacterial biotoxins

<table>
<thead>
<tr>
<th>Bacterial biotoxins</th>
<th>Etiologic agent</th>
<th>Natural reservoirs</th>
<th>Potential vehicles of transmission</th>
<th>Possible biological warfare modes of delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clostridium botulinum</em> toxins</td>
<td>(collectively BTX)</td>
<td>Soil, animals, fish</td>
<td>Foodborne with consumption of food contaminated by <em>C. botulinum</em> toxins, wound infection from exposure to toxin spores</td>
<td>Primarily aerosol release during biowarfare attack; intentional contamination of food and water possible</td>
</tr>
</tbody>
</table>
### Clostridium perfringens

<table>
<thead>
<tr>
<th>Toxins</th>
<th>Description</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and gastrointestinal tract of healthy humans and animals</td>
<td>Foodborne with clostridial food poisoning, wound contamination with <em>C. perfringens</em> spores</td>
<td>Primarily as aerosol threat during biowarfare attack, toxin may be delivered in combination with other toxins, waterborne contamination conceivable but unlikely</td>
</tr>
</tbody>
</table>

### Staphylococcus enterotoxin B (SEB)—including protein toxin from *Staphylococcus aureus*

<table>
<thead>
<tr>
<th>Description</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humans, contaminated milk and milk products</td>
<td>Foodborne through ingestion of food, milk, and milk products containing the preformed toxin</td>
</tr>
</tbody>
</table>

### Fungal-derived biotoxins (mycotoxins)

<table>
<thead>
<tr>
<th>Toxin</th>
<th>Description</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aflatoxin</td>
<td>Variety of agricultural plants including peanuts</td>
<td>Foodborne through ingestion of contaminated food</td>
</tr>
<tr>
<td>Metabolite of <em>Aspergillus flavus</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-2 mycotoxin</td>
<td>Grain infected with <em>Fusarium</em> mold</td>
<td>Foodborne through ingestion of food prepared with moldy grain</td>
</tr>
<tr>
<td>Extract from <em>Fusarium</em> spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatoxin A</td>
<td>Freshwater cyanobacteria (<em>Anabaena flos-aquae</em>)</td>
<td>Waterborne</td>
</tr>
<tr>
<td>Product of cyanobacteria, <em>Anabaena flos-aquae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microcystins</td>
<td>Freshwater blooms of cyanobacteria (<em>Microcystis spp.</em>)</td>
<td>Waterborne</td>
</tr>
<tr>
<td>Products of cyanobacteria, <em>Microcystis spp.</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Continued)
### Table 2 (Continued)

<table>
<thead>
<tr>
<th>Etiologic agent</th>
<th>Natural reservoirs</th>
<th>Potential vehicles of transmission</th>
<th>Possible biological warfare modes of delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ricin</strong></td>
<td>Castor bean (<em>Ricinus communis</em>)</td>
<td>Airborne through inhalation during industrial operations, foodborne through ingestion of castor bean meal</td>
<td>Potential aerosol threat, delivery through injection, possible contamination of food and water</td>
</tr>
<tr>
<td><strong>Marine biotoxins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saxitoxin [Paralytic shellfish poisoning (PSP)]—product of dinoflagellate, <em>Gonyaulax</em></td>
<td>Shellfish</td>
<td>Foodborne by ingesting bivalve mollusks with accumulated dinoflagellates</td>
<td>Primary threat through aerosol release, delivery by injection or projectiles, contamination of food and water supplies</td>
</tr>
<tr>
<td>Tetrodotoxin Neurotoxin from pufferfish sp.</td>
<td>Pufferfish</td>
<td>Foodborne through consumption of improperly prepared pufferfish</td>
<td>Possible aerosol form, possible water contamination threat</td>
</tr>
</tbody>
</table>

'aThis summary table is a compilation of information from several resources (9, 13, 17, 23, 28, 30, 37–39, 42, 44, 46, 59, 62) and is intended for educational purposes only. This resource is not intended to be an exhaustive or comprehensive review of the epidemiologic or medical features of each biological agent nor is it intended to be construed as a definitive list of potential biowarfare threats.

'bModified and reprinted with permission from the author and Arnot Ogden Medical Center (46).
diagnostic challenge were apparent after the deliberate release of weaponized *Bacillus anthracis* via the U.S. postal system in 2001 (31). With 22 confirmed cases and five deaths, this biological attack necessitated a change in the approach to the practice of medicine and public health in the United States. The following sections of this review provide a synopsis of the clinical approach and enhanced knowledge base necessary to diagnose waterborne disease resulting from intentional biological pathogen and biotoxin exposure.

**DIAGNOSIS OF WATERBORNE DISEASE RESULTING FROM BIOLOGICAL PATHOGEN EXPOSURE**

In theory, any microbial pathogen could be used as a biological weapon, but in reality, the list of weaponized biological pathogens that pose a significant public health threat is restricted. However, the threat list will continue to be dynamic (37, 42, 46), and the changing nature and number of potential biological pathogens that could be used to intentionally contaminate water also remains uncertain, which adds to the clinical challenge of accurate and timely diagnosis. Health care and public health practitioners will face many diagnostic dilemmas when attempting to accurately diagnose and appropriately manage waterborne disease resulting from intentional contamination of water supplies and the water environment with biological pathogens. Although weaponized biological pathogens are most effectively delivered as aerosolized particles, alternative modes of delivery and routes of exposure include intentional contamination of food and water systems and supplies (7, 9, 23, 30, 35, 39, 42). Biological pathogens that have been identified as potential biowarfare agents and that may cause waterborne disease include bacterial, parasitic, viral, and rickettsial and rickettsial-like pathogens (see Table 2).

**DIAGNOSIS OF WATERBORNE DISEASE RESULTING FROM BIOTOXIN EXPOSURE**

Biological toxins or biotoxins are also attractive biological warfare weapons owing to their severe toxicity and comparative ease of production (5). Biological toxins are an important and complex group of potential biowarfare agents that result from natural metabolites of bacteria, fungi, plant and algal, or marine species (42). These natural biotoxins are considered to be some of the most toxic substances known to man; lethal doses are often expressed in nanograms of exposure (5, 23). In general, most weaponized biotoxins have been developed primarily for aerosolized application and dissemination in military and civilian populations (62). However, many biotoxins are considered to be potential waterborne threats and would be effective contaminants in drinking water under suitable conditions (42, 62). The potential range of biotoxins available for direct and indirect contamination of water supply systems is significant (39). Many of the biotoxins of public health concern are stable in water and may not produce readily detectable changes in the physical characteristics of water (42, 62). Biotoxins that have been identified as potential biowarfare agents and that may cause waterborne disease include bacterial biotoxins, mycotoxins, fungal-, plant-, or algal-derived biotoxins, and marine biotoxins (see Table 2).
Many biotoxins are very stable under normal environmental conditions and produce serious symptoms when ingested, inhaled, or introduced into the body by other methods (23). Biological toxins display a broad range of physical and chemical characteristics and varied mechanisms of action, which results in a diverse spectrum of health effects ranging from minor illness to death in humans (5, 23).

Biological toxins including aflatoxins, botulinum toxins, and ricin have already been weaponized, and possible weaponization of other biotoxins may have been accomplished including microcystins, saxitoxin, T-2 mycotoxin, staphylococcal enterotoxins, and tetradotoxin (9, 62). There is evidence to suggest that natural production of microcystins found in stagnant bodies of water could produce enough biotoxin to cause illness in human populations if these bodies of water are used for public drinking water consumption (28, 40). Biotoxins are complex chemical compounds with varying solubilities, reaction rates, and degradation products in the water environment (28, 64). In addition, a specific toxin may display varying environmental stability and toxicity in water even within species type, such as for botulinum toxin with variation among types A, B, C, D, and E (56).

Biotoxin exposure and subsequent disease may be easily misdiagnosed if the diagnosis is not strongly suspected early during initial case presentation and in the early evaluation phase of a waterborne outbreak investigation (10). Biotoxins such as botulinum toxin may be stable for several days in untreated water or beverages, and, to prevent misdiagnosis, these potential contaminant sources should be included in an exposure history as a possible mode of dispersal of the biotoxin (3). Naturally occurring toxic blooms of cyanobacterial biotoxins have created potential health hazards in both drinking and recreational water (63). Therefore, recreational water exposure will also need to be included in a thorough exposure history to prevent a missed diagnosis of a possible intentional contamination event with certain biotoxins.

Use of Diagnostic Indicators and Epidemiologic Patterns to Diagnose Biowarfare Agent Exposure and Waterborne Disease

Even though specific detection methods for recognizing intentional contamination of water systems are improving rapidly (59), the most likely initial indication that a water contamination event has occurred will be a change in disease trends and illness patterns and possibly a community-wide waterborne disease outbreak. Therefore, the first indication of a terrorist attack may be an increased number of patients presenting to their health care provider or hospital emergency department with unusual or unexplained illness or injury (23, 29, 35). Frequently, humans are the most sensitive or only detectors, in many cases, of an intentional bioterrorist agent release, including the route of waterborne exposure (21, 29, 48). Consequently, the medical and public health community may provide the initial warning of intentional contamination of water and must understand their critical role as front-line responders in detecting water-related disease resulting from biological terrorism. Early presenting symptoms of waterborne biological warfare agents may
be nonspecific and mimic more common endemic diseases and medical disorders. However, certain clinical manifestations and disease syndromes may be characteristic of a terrorist attack using the route of waterborne exposure to biological warfare agents.

Several published epidemiologic patterns and clinical sentinel clues provide a valuable resource for both the medical and public health community facing the challenges of diagnosing terrorism-related illness and injury (8, 11, 23, 34, 38, 44, 48, 51). These epidemiologic indicators may result from multiple exposure pathways including water and have universal application in a clinical and public health setting (see Table 3).

Use of Syndromic Surveillance and Disease Trends to Assist in the Diagnosis of Waterborne Terrorism

Although diagnostic laboratory testing, public health surveillance, and notifiable disease reporting have been enhanced since September 11, 2001, these systems may not be able to detect an evolving terrorist event or emerging outbreak (8). One method to supplement these traditional sources of public health “intelligence” is to employ syndromic surveillance, which utilizes the recognition of characteristic signs and symptoms of large groups of presenting patients usually at hospital emergency departments (8, 30, 51, 54). Embracing the use of syndromic surveillance as a diagnostic tool has the potential for enhancing early recognition of suspected cases of terrorism-related waterborne disease or waterborne outbreaks resulting from intentional water contamination (8, 30, 38, 51).

The benefit of using this approach to detect terrorism-related waterborne disease is based on the fact that syndromic surveillance monitors disease trends by grouping cases into syndromes rather than by specific diagnoses. Several state and local health departments are developing and implementing syndromic surveillance systems to complement traditional diagnosis-based surveillance systems (4). For the medical community, syndromic surveillance systems may augment emergency room and hospital diagnosis-based surveillance by adding the ability to quickly identify clusters of acute illness resulting from potential terrorism exposure (41).

Medical and public health practitioners should maintain a high level of suspicion for the following types of syndromes or clusters of disease in their patient populations or public health districts, which may indicate possible biowarfare agent exposure (8, 30, 54), including the use of water as a potential exposure route (46):

- gastroenteritis of an apparent infectious etiology or acute biotoxin exposure;
- upper and lower respiratory disease with fever and sudden death of previously healthy patients;
- rash of synchronous vesicular or pustular lesions and fever;
- suspected meningitis, encephalitis, and encephalopathy;
- sepsis or nontraumatic shock;
- unexplained death with a history of fever; and
TABLE 3  Epidemiologic indicators and sentinel clues indicating possible biowarfare agent exposure and illness\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point source illness and injury patterns</td>
<td>With record numbers of severely ill or dying patients presenting within a short period of time</td>
</tr>
<tr>
<td>Very high attack rates</td>
<td>With 60%--90% of potentially exposed patients displaying symptoms or disease</td>
</tr>
<tr>
<td>Severe and frequent disease manifestations in previously healthy patients</td>
<td>Increased and early presentation of immunocompromised patients and vulnerable population patients with debilitating disease because the dose of inoculum or biotoxic exposure required to cause disease may be less than for the general healthy population</td>
</tr>
<tr>
<td>“Impossible epidemiology” with naturally occurring diseases diagnosed in geographic regions where the disease has not been encountered previously</td>
<td></td>
</tr>
<tr>
<td>Higher than normal numbers of patients presenting with gastrointestinal, respiratory, neurologic, and fever diagnoses</td>
<td>Record number of fatal cases with few recognizable signs and symptoms, indicating lethal doses near a point of dissemination or dispersal source of biological pathogen or biotoxin</td>
</tr>
<tr>
<td>Localized areas of disease epidemics that may occur in a specific neighborhood or sector, possibly indicating contamination of a selected point in a posttreatment water distribution system</td>
<td>Multiple infections at a single location (school, hospital, nursing home) with an unusual or rare biological pathogen</td>
</tr>
<tr>
<td>Lack of response or clinical improvement of presenting patients to traditional treatment modalities</td>
<td>Near simultaneous outbreaks of similar or different epidemics at the same or different locations, indicating an organized pattern of intentional biological agent release</td>
</tr>
<tr>
<td>Endemic disease presenting in a community during an unusual time of the year or found in a community where the normal vector of transmission is absent</td>
<td>Unusual temporal or geographic clustering of cases with patients attending a common public event, gathering, or recreational venue</td>
</tr>
<tr>
<td>Increased patient presentation with acute neurologic illness or cranial nerve impairment with progressive generalized weakness</td>
<td>Unusual or uncommon route of exposure of a disease such as illness resulting from a waterborne agent not normally found in the water environment</td>
</tr>
</tbody>
</table>

\textsuperscript{aSeveral epidemiologic patterns are presented above that have been identified as possible sentinel clues of a terrorist attack from several public health and military sources (8, 11, 23, 34, 38, 44, 48, 51). None of these indicators alone is pathognomonic for terrorism-related disease, but they are presented as an educational tool for use by health care providers and public health practitioners as possible disease trends that may warrant further investigation.}

\textsuperscript{bModified and reprinted with permission from the author and Arnot Ogden Medical Center (46).}
advancing cranial nerve impairment with progressive generalized weakness.

None of these indicators alone are pathognomonic for terrorism-related disease but represent disease trends that may warrant further investigation.

WEB-BASED RESOURCES AND CLINICAL TOOLS FOR WATERBORNE DISEASE AND WATER TERRORISM

Quick access to constantly updated and credible clinical information could assist most health care providers and public health practitioners to rapidly evaluate, manage, and prevent disease resulting from exposure to biowarfare agents (32, 38), including exposure from water sources (46). Results of a national survey of approximately 1000 family physicians conducted in 2002 revealed that the greatest predictor of responding appropriately to bioterrorism was “knowing how to get information in the event of a suspected attack”—this includes clinical information (16). The need of the medical and public health community for immediate access to specialized information and reference materials is extremely important when addressing the recognition and management of acts of water terrorism, particularly if a public drinking water system is contaminated. In addition, the initial medical and public health response required to address an act of water terrorism will be inherently a local or regional challenge until external resources become available to a community (46). The American Medical Association estimates that local medical and public health responders may need to function unassisted for up to 6–8 hours until outside resources arrive, in the event of a terrorist attack (1).

An online clinical resource guide and management tool has been developed for health care practitioners and public health specialists faced with addressing the evaluation and management of water-related disease resulting from terrorist activity (45, 46). This free resource is posted as part of the physician online guide, Recognizing Waterborne Disease and the Health Effects of Water Pollution (http://www.WaterHealthConnection.org; Figures 2 and 3). The primary purpose and educational intent of the terrorism preparedness tool, Physician Preparedness for Acts of Water Terrorism, is to provide the medical and public health community with streamlined access to resources that will help guide them through the recognition, management, and prevention of water-related disease resulting from intentional acts of water terrorism. This web-based educational program has been peer-reviewed by medical, public health, and military experts and has received, in the first 18-month period online, more than 7 million hits or requests for information from members of the medical and public health community from across the United States. Sustained use of these types of terrorism preparedness resources and targeted education of the medical and public health community are essential strategies for the continued protection and security of water supplies in the United States and for the prevention of waterborne disease resulting from intentional acts of water terrorism.
ACKNOWLEDGMENTS

The author thanks the Environmental Protection Agency, Arnot Ogden Medical Center, and the American Water Works Association for providing funding during the development and ongoing maintenance of the http://www.WaterHealthConnection.org Web site highlighted in this review. The author also extends a special thanks to Ms. Laura Campbell for her extremely valuable assistance and extraordinary expertise during the preparation of this manuscript.

The Annual Review of Public Health is online at http://publhealth.annualreviews.org

LITERATURE CITED

235


WATER AND BIOTERRORISM


32. Greenough PG. 2002. Infectious diseases and disasters. See Ref. 34a, pp. 23–33


36. Kaufmann AF, Meltzer MI, Schmid GP.
MEINHARDT


Figure 2  Recognizing Waterborne Disease and the Health Effects of Water Pollution: Physician On-line Reference Guide is accessible at http://www.WaterHealthConnection.org (45).
CONTENTS

**Epidemiology and Biostatistics**

A Life Course Approach to Chronic Disease Epidemiology, *John Lynch and George Davey Smith* 1

Advances in Cancer Epidemiology: Understanding Causal Mechanisms and the Evidence for Implementing Interventions, *David Schottenfeld and Jennifer L. Beebe-Dimmer* 37

Competing Dietary Claims for Weight Loss: Finding the Forest Through Truculent Trees, *David L. Katz* 61

Population Disparities in Asthma, *Diane R. Gold and Rosalind Wright* 89

The Rise and Fall of Menopausal Hormone Therapy, *Elizabeth Barrett-Connor, Deborah Grady, and Marcia L. Stefanick* 115


**Environmental and Occupational Health**

Advances in Risk Assessment and Communication, *Bernard D. Goldstein* 141

EMF and Health, *Maria Feychting, Anders Ahlbom, and Leeka Kheifets* 165

The Public Health Impact of Prion Diseases, *Ermias D. Belay and Lawrence B. Schonberger* 191


**Public Health Practice**

Economic Causes and Consequences of Obesity, *Eric A. Finkelstein, Christopher J. Ruhm, and Katherine M. Kosa* 239


New Microbiology Tools for Public Health and Their Implications, *Betty H. Robertson and Janet K.A. Nicholson* 281
CONTENTS

The Public Health Infrastructure and Our Nation’s Health,
Edward L. Baker, Jr., Margaret A. Potter, Deborah L. Jones,
Shawna L. Mercer, Joan P. Cioffi, Lawrence W. Green,
Paul K. Halverson, Maureen Y. Lichtveld, and David W. Fleming
303
Social Marketing in Public Health, Sonya Grier and Carol A. Bryant
319
Urban Health: Evidence, Challenges, and Directions, Sandro Galea
and David Vlahov
341

SOCIAL ENVIRONMENT AND BEHAVIOR

Urban Health: Evidence, Challenges, and Directions, Sandro Galea
and David Vlahov
341
Acculturation and Latino Health in the United States: A Review of the
Literature and its Sociopolitical Context, Marielena Lara,
Cristina Gamboa, M. Iya Kahramanian, Leo S. Morales,
and David E. Hayes Bautista
367
Adolescent Resilience: A Framework for Understanding Healthy
Development in the Face of Risk, Stevenson Fergus and
Marc A. Zimmerman
399
Declining Rates of Physical Activity in the United States: What are
the Contributors? Ross C. Brownson, Tegan K. Boehmer,
and Douglas A. Luke
421
Impact of Nicotine Replacement Therapy on Smoking Behavior,
K. Michael Cummings and Andrew Hyland
583
Primary Prevention of Diabetes: What Can Be Done and How Much
Can Be Prevented?, Matthias B. Schulze and Frank B. Hu
445
Psychosocial Factors and Cardiovascular Diseases, Susan A. Everson-Rose
and Tené T. Lewis
469
Social Marketing in Public Health, Sonya Grier and Carol A. Bryant
319

HEALTH SERVICES

Abortion in the United States, Cynthia C. Harper, Jillian T. Henderson,
and Philip D. Darney
501
Patient Perceptions of the Quality of Health Services, Shoshanna Sofaer
and Kirsten Fimming
513
Toward a System of Cancer Screening in the United States: Trends
and Opportunities, Nancy Breen and Helen I. Meissner
561
Competing Dietary Claims for Weight Loss: Finding the Forest Through
Truculent Trees, David L. Katz
61
Urban Health: Evidence, Challenges, and Directions, Sandro Galea
and David Vlahov
341