# 12

# EFFECT OF MICROBES ON HUMAN HEALTH

Higher organisms evolved in a microbial world. From the perspective of microorganisms, plants and animals represent another environment to colonize. Thus, it is not surprising that humans, as well as other animals and plants, have a diverse community of microbes living on and in them. Some of these "passengers" are normal, beneficial, or even necessary (e.g., rhizobia in some plants; cellulose degraders in animals such as termites and ruminants), whereas others are abnormal, harmful, or even fatal.

## 12.1 MICROBIAL COLONIZATION OF HUMANS

The human body is a highly complex, multicellular life form whose structure and function depends on the coordinated interaction of roughly 10 trillion individual cells. On a microscopic level, the average human also carries a similar number of nonhuman visitors living opportunistically on and within the body. Freshly scrubbed and brushed, therefore, your body may outwardly appear clean and wholesome, but it is anything but sterile.

Your body is the mobile, warm-blooded equivalent of an ocean's coral reef, supporting a vast and highly divergent range of life. These microbes stretch from head to toe, spread across your skin, hide in the crevices of your mouth and nose, and follow your food from start to finish. Their presence is not just normal, but helpful or even necessary.

The life-style of these microorganisms is often described as a commensal relationship, in which they are tolerated by or even offer certain benefits to their host. For example, microbes are commonly found within the human intestinal tract, where they help to digest some foods and produce essential nutrients such as vitamins $B_{12}$, K, thiamin, riboflavin, and pyroxidine.

*Environmental Biology for Engineers and Scientists*, by David A. Vaccari, Peter F. Strom, and James E. Alleman






Perhaps even more important, the skin's normal biota actually offers a protective effect known as **colonization resistance**, which effectively safeguards the body against a hostile takeover by **pathogenic** (disease-causing) microbes. This effect can readily be appreciated during those periods when broad-spectrum antibiotics are used to combat a disease. The associated stress imposed on a body's normal biota can then lead to invasion by opportunistic, abnormal microbes (e.g., excessive growths of fungi such as *Candida*), which may lead to secondary health problems.

The composition of the human-associated microbial community will vary to some extent from one person to the next, and to some degree may also change with time. However, Table 12.1 provides a basic overview of the common locations and examples of the makeup of this normal microbial biota.

### 12.1.1 Abnormal Microbial Infection

Although the vast majority of microbes pose no threat whatsoever to human health, there are many forms that are outright hazards. The importance of the infectious diseases they cause is demonstrated by the rates of **mortality** (death) to which they can be linked. Even today, infectious disease is the world's leading cause of death, with fatalities exceeding 15 million per year (Figure 12.1). Rates of overall **morbidity** (illness, both fatal and nonfatal) are of course much higher and have a tremendous impact on the world's economy and each person's quality of life.

Respiratory and gastrointestinal diseases account for over half of these deaths. It is also sad to note that the majority of these deaths are of children below the age of 5 (the criterion used for **infant mortality**). Underdeveloped or developing countries are most heavily hit. Within industrialized countries such as the United States, for instance, the infant mortality rates fall below 1%, but these figures skyrocket to nearly 10% in developing countries and to more than 15% in the world's least developed countries. Furthermore, about half of the world's population is considered to be at risk to a wide range of infectious diseases.

Indeed, within the past millennia, microbial disease has proven to be a formidable adversary, one that has the potential to decimate the human population if left unchecked. During the Middle Ages and extending into the nineteenth century, diseases such as bubonic plague, cholera, and typhoid swept through Europe, causing massive mortality. The influenza pandemic at the end of World War I, for example, killed more people than the war itself.

Microorganisms are ubiquitous on and within the bodies of virtually all higher lifeforms (excluding those raised in laboratories under special "germ-free" conditions), and for the most part they are innocuous for their **host** (the organism that supports them). However, abnormal proliferation of indigenous microbes, or invasion from an external source, can lead to disease. Most of the important problems are infectious in nature, being spread by the dissemination of viable, pathogenic cells from one host to another by either direct or indirect means. In many instances, pathogenic microbial agents may also subsist within an environmental reservoir, lingering in wait for an opportunity to assert their influence.

A **parasite** is an organism that lives in a close relationship with another organism, benefiting at the expense of its host. **Pathogens** are thus parasites that do enough harm to their host to result in disease. However, it is also common to call disease-producing viruses, bacteria, and fungi *pathogens*, while referring to infective protozoans and worms as *parasites*.

**TABLE 12.1 Examples of Normal Microbial Biota of Human Body Regions**[a]

| Region | Examples |
|---|---|
| Skin | *Acinetobacter*<br>*Corynebacterium*<br>*Propionibacterium acnes*<br>*Staphylococcus aureus*<br>*Staphylococcus epidermidis*<br>*Streptococcus* |
| Nose, nasopharynx, and sinuses | *Haemophilus*<br>*Neisseria*<br>*Staphylococcus aureus*<br>*Staphylococcus epidermidis*<br>*Streptococcus pneumoniae*<br>*Streptococcus pyogenes* |
| Mouth and throat | *Corynebacterium*<br>*Fusobacterium*<br>*Neisseria*<br>*Staphylococcus epidermidis*<br>*Streptococcus mitis*<br>*S. salivarius*<br>*Treponema* |
| Lower respiratory tract | Normally, few microorganisms |
| Stomach (pH ~ 2) | *Helicobacter pylori*<br>*Lactobacillus* |
| Small intestine (pH ~ 4–5) | *Enterococcus*<br>*Lactobacillus* |
| Large intestine (colon) (pH ~ 7) | *Bacteroides*<br>*Clostridium*<br>*Enterococcus faecalis*<br>*Escherichia coli*<br>*Eubacterium*<br>*Lactobacillus* |
| Urethra | *Escherichia coli*<br>*Proteus mirabilis* |
| Vagina | *Candida* (yeast)<br>*Escherichia coli*<br>*Lactobacillus acidophilus*<br>*Streptococcus* |

[a]All are bacteria, except *Candida*, a fungus.

***The Germ Theory of Disease and Koch's Postulates*** We now take for granted that infectious diseases are caused by microbes, but this is actually a relatively new concept. Although Leeuwenhoek (Section 10.2.1) had first observed microbes in the seventeenth century, they were generally thought to be too small and unimportant to affect the health of higher organisms. In the early nineteenth century, fungal diseases of plants and later animals (silkworms) were first recognized. When Pasteur (Section 10.2.2) summarized his findings on the **germ theory of disease** in 1862, and referred to microbially caused spoilage as "diseases" of wine and beer, this influenced Englishman Joseph Lister to theorize that surgical wound infections might be the result of bacterial growth. His



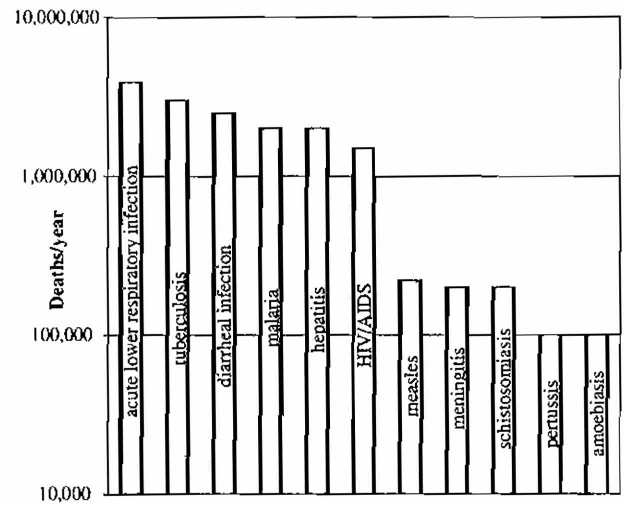


**Figure 12.1** Infectious diseases with annual global mortalities of at least 100,000.

development of antiseptic surgical techniques in 1864 succeeded in greatly reducing the number of such often fatal outcomes. In 1873, Norwegian physician Gerhard Henrik Armauer Hansen, who oversaw a leper hospital, proposed that a specific bacterium (now called *Mycobacterium leprae*) was responsible for leprosy.

However, it was not until the definitive work of German Robert Koch (Figure 12.2) in 1876 that bacteria were proven to be agents of disease. About 10 years earlier, C. J. Davaine and others had shown that rod-shaped bacteria were present in the blood of animals suffering from anthrax (an important disease of animals, occasionally transmitted to humans), but not in that of healthy animals, and that an injection of infected blood would cause anthrax in previously uninfected animals. Koch provided the final proof of the bacterial **etiology** (causation) of anthrax by isolating the organism (now called *Bacillus anthracis*), growing it in pure culture in the laboratory, and injecting it into healthy mice, which then developed anthrax.

Koch was thus the first to meet the criteria for proving the causative relationship between a microorganism and a specific disease, as proposed in 1840 by German J. Henle (one of Koch's teachers). These are now referred to as **Koch's postulates**:

1. The microbial agent must be present in every diseased organism, but not in healthy organisms.
2. The agent must be isolated from the diseased host and grown in pure culture.
3. Inoculation of a healthy susceptible host with the pure culture must result in the same disease.
4. The same agent must be recoverable from the experimentally infected host.

These postulates, which Koch published in 1884 following his work on tuberculosis (which later won a Nobel prize), still represent an important benchmark used to judge whether there is a causal relationship between a particular microbe and a given disease.

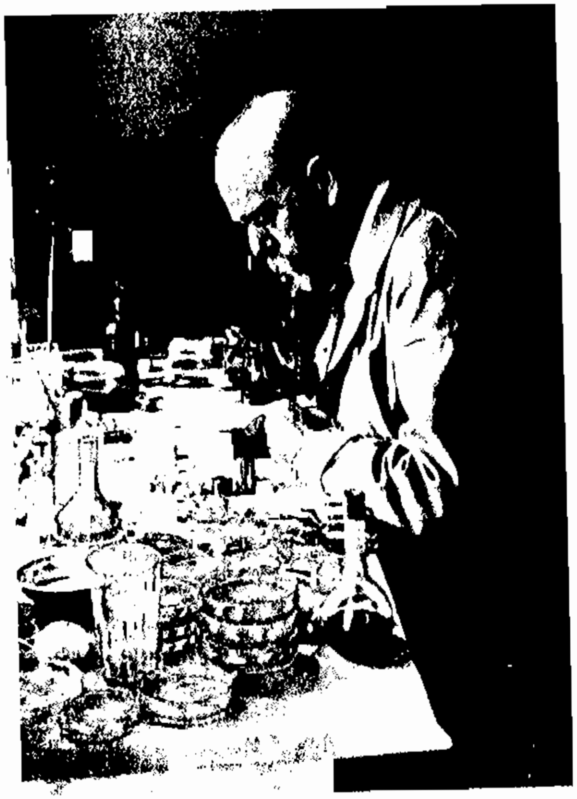

**Figure 12.2** Robert Koch. (Photo by F. H. Hancox, 1896.)

The methods that Koch developed also helped lead to rapid identification of numerous other causative agents of disease (Table 12.2).

***Prevalence and Distribution of Diseases*** Diseases can vary widely in their **prevalence** (fraction of individuals infected) and geographic distribution. **Epidemiologists** (scientists who study diseases and their transmission) refer to an **endemic** disease as one that is constantly present in a specific area, usually at a low level (relatively few affected individuals). An **epidemic** refers to a disease with an unusually high prevalence in a specific geographical area. A **pandemic** is a widespread—nearly global—epidemic. The term **outbreak** is used to describe a sudden increase in the prevalence of a disease in a specific population; this may be associated with a single source, such as a contaminated water supply or food. Each victim may be called a **case**.

***Disease Transmission*** A disease **reservoir** is a site in which an infectious agent remains viable so that it can serve as a source of infection for new hosts. Commonly, this is the pool of already infected hosts, so that humans are the primary reservoir for many human diseases. However, some disease organisms can also infect other species, and some go through a complex life cycle in which the host species alternate for the various life stages.



**TABLE 12.2 Chronology of Some Major Disease Agent Discoveries**

| Disease | Microbial Agent[a] | Discoverers | Year |
|---|---|---|---|
| Anthrax | *Bacillus anthracis* | Koch | 1876 |
| Gonorrhea | *Neisseria gonorrhoeae* | Neisser | 1879 |
| Malaria | *Plasmodium* spp. | Laveran | 1880 |
| Tubercolosis | *Mycobacterium tuberculosis* | Koch | 1882 |
| Cholera | *Vibrio cholerae* | Koch | 1883 |
| Diphtheria | *Corynebacterium diphtheriae* | Klebs and Loeffler | 1883–1884 |
| Typhoid fever | *Salmonella typhi* | Gaffky | 1884 |
| Diarrhea | *Escherichia coli* | Escherich | 1885 |
| Tetanus | *Clostridium tetani* | Nicolaier and Kitasato | 1885–1889 |
| Pneumonia | *Streptococcus pneumoniae* | Fraenkel | 1886 |
| Meningitis | *Neisseria meningitidis* | Weichselbaum | 1887 |
| Gas gangrene | *Clostridium perfringens* | Welch and Nuttal | 1892 |
| Plague | *Yersinia pestis* | Kitasato and Yersin | 1894 |
| Botulism | *Clostridium botulinum* | Van Ermengem | 1896 |
| Dysentery | *Shigella dysenteriae* | Shiga | 1898 |
| Syphilis | *Treponema pallidum* | Schaudin and Hoffmann | 1905 |
| Whooping cough | *Bordella pertussis* | Bordet and Gengou | 1906 |
| Rocky Mountain spotted fever | *Rickettsia rickettsii* | Ricketts | 1909 |
| Tularemia | *Francisella tularensis* | McCoy and Chapin | 1912 |

[a]All are bacteria, except *Plasmodium*, a protozoan.

A disease mainly of animals that also can be transmitted to humans (such as anthrax) is called a **zoonosis** (plural, *zoonoses*). Some infectious agents are able to survive in the environment, outside any host. This includes some species, referred to as **opportunistic pathogens**, which normally grow in soil or water or other environments but are capable of infecting a host that is **compromised** (weakened) by an injury, condition, or disease.

The human reservoir may include both people with the disease and those who are infected but show no symptoms. Individuals with such **subclinical** infections are referred to as asymptomatic **carriers**. The most notorious example of a carrier was Mary Mallon, known as "Typhoid Mary." Although she showed no symptoms herself, she was the source of a number of typhoid outbreaks in the New York City area in the early twentieth century. Because she refused to stop working as a food handler, eventually she was jailed.

One source of infection is the native microorganisms living on or in an individual. As a result of some change in it (increased **virulence**, the ability to cause disease) or (more commonly) the host, this usually innocuous **indigenous** microbe may become pathogenic. For example, the common intestinal *Escherichia coli* can acquire a virulence factor leading to severe diarrhea, the common skin inhabitant *Staphylococcus aureus* can cause serious illness after being transferred into formerly sterile tissue as the result of a subcutaneous wound penetration, or a fungal vaginal infection can result from suppression of the normally dominant bacterial populations because of antibiotic use.

However, in most cases an infectious agent must be **transmitted** from one host to another. This transmission may be relatively direct or may involve an intermediate. Direct transmission occurs through contact or exchange of bodily fluids between an infected host and the new, previously noninfected host. Rabies and sexually transmitted diseases such as syphilis are spread in this way. Many skin diseases, such as ringworm, are also transmitted via direct contact, but they may also be spread indirectly on objects (such as towels) because the causative agent can persist in the environment for a sufficient period of time. Most respiratory diseases are **droplet infections**, spread through **aerosols** (liquid or solid particles in air) resulting from exhaling, sneezing, or coughing. These remain suspended briefly in the air (during which time the agents remain viable), then are inhaled by the new host. Thus, the transmission is not truly direct, but is still generally considered to be so because the time in the air is so short (minutes or less). It is now believed that the common cold often is spread by direct contact through the following scenario: an infected person's hand becomes infectious when it touches the fluids of his or her mouth, nose, or eye; transmission occurs when he or she touches another person's hand; the new host becomes infected when touching his or her own mouth, nose, or eye.

Indirect transmission occurs through some other medium. A nonliving material that is capable of infecting a large number of individuals is referred to as a **vehicle**. Food and water are the two most common. Air can also be considered a vehicle, provided that the infectious agent is able to survive in this usually hostile (mainly because of drying and ultraviolet radiation) environment. Other nonliving means of transmission, such as clothing, furniture, toys, doorknobs, and bandages, are referred to as **fomites**.

A living intermediate for indirect transmission is called a **vector**. Many common vectors are biting insects (e.g., mosquitoes, malaria and some types of encephalitis; fleas, plague; lice, typhus; and flies, sleeping sickness) or ticks (Lyme disease and Rocky Mountain spotted fever). The vector picks up the infectious agent when it bites an infected host, then transmits it to a new host with another bite. In many cases the infectious agent reproduces within the vector (which is then considered an alternate host), thus increasing the likelihood of successful transmission to the next host. However, in some cases an organism such as a nonbiting fly is simply a mechanical vector, transporting the infectious agent from host to host on its mouth parts, feet, wings, or body hairs.

Not every transmission of a pathogen to a new potential host results in infection and disease. First, the host must be susceptible—a species that the pathogen can parasitize, and without previously developed **immunity** (resistance) from vaccination or prior exposure. Also, at least a minimum quantity of pathogens, called an **infective dose**, must be transmitted. Although for a few pathogens (perhaps the virus hepatitis A or the roundworm *Ascaris*) only a single viable particle (e.g., cell, spore, cyst, egg) may be sufficient, it more commonly takes at least tens (e.g., the bacterium *Shigella* and the protozoans *Entamoeba histolytica*, *Cryptosporidium parvum*, and *Giardia lamblia*), thousands (*Vibrio cholerae*), or even millions (e.g., *Salmonella*, *Clostridium perfringens*) of pathogens to overcome a healthy body's defense mechanisms and produce disease.

***Example 12.1*** While hiking in a national forest, a group of healthy young adults drinks from a clear mountain brook. Unknown to them, a short distance upstream there is a colony of beaver that has been infected with *Giardia lamblia*, and the water they consumed contains 2 viable cysts/mL. How much could a person probably drink without developing giardiasis, assuming that the infective dose is 20 cysts?

*Solution* If the number of cysts likely to result in disease is 20, a person could drink

$$20\,\text{cysts} \div 2\,\text{cysts/mL} = 10\,\text{mL}$$

or about 2 teaspoons. Thus the hikers are likely to develop giardiasis.



Not all people show equal resistance to disease, and individual resistance also varies over time. In general, the very young and very old have weaker immune systems, and some diseases may also severely compromise the ability to fight off other infections. This is of special concern in hospitals, since patients are typically in poorer health than is the general population, and thus more susceptible to contracting additional diseases. A **nosocomial** infection is one that is acquired in a hospital. In the United States alone, about 100,000 deaths per year occur from such infections, making them the fourth highest killer here (after heart disease, cancer, and strokes).

Parasites and their hosts evolve together over time. In general, it is not in the "interest" of a pathogen to kill its host. In fact, some fatal diseases, such as rabies and plague, are actually zoonoses, with humans an accidental (and therefore unadapted) host. Cholera, which is a human disease, appears to have grown somewhat milder over the last two centuries. Other human diseases remain fatal, however, perhaps because they have not sufficiently evolved yet. Also, previously unexposed populations may be particularly susceptible to a disease. This was the case, for example, among the indigenous peoples of North America when smallpox and measles were introduced from Europe.

***Routes of Infection*** There are several logical ways in which to classify diseases. One way is by the region of the body that is infected, such as respiratory disease, gastrointestinal illness, or urinary tract infection. Another is to group diseases by their causative agents, such as diseases caused by particular types of bacteria or viruses. However, for environmental engineers and scientists, it is usually most helpful to categorize diseases by their mode of transmission.

That is the approach that is taken here. In the following sections we look at diseases transmitted by water, food, air, vectors, sexual activity, and other direct contact. This is somewhat arbitrary, since a single disease may be spread by more than one route (e.g., water and food). The greatest emphasis is placed on waterborne disease, since this is where the role of the environmental engineer and scientist is greatest.

Table 12.3 provides an alphabetical listing of many diseases, along with their causative agents and mode of transmission. Although the list is certainly not all-inclusive, an effort was made to list all diseases mentioned in this and other chapters.

**TABLE 12.3 Selected Diseases of Humans, Their Causative Agents, and Major Modes of Transmission**

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Abscesses, boils | *Staphylococcus aureus* | b-7 | C-w; I | Most common agent |
| African sleeping sickness | *Trypanosoma gambiense, T. rhodesiense* | p-f | V-tsetse fly | Trypanosomiasis |
| Amoebic dysentery | *Entamoeba histolytica* | p-a | W-f/o | Amebiasis |
| Anthrax | *Bacillus anthracis* | b-7 | C-d; A | Zoonosis—sheep, cattle; usually contracted through cuts in skin; airborne as biological weapon |

(*Continued*)

**TABLE 12.3** *(Continued)*

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Aquired immune deficiency syndrome (AIDS) | Human immuno deficiency virus (Retroviridae) | v | S; C-b | |
| Ascariasis | *Ascaris lumbricoides* | w-n | F-f/o | Ingestion of contaminated soil or plants |
| Aspergillosis | *Aspergillus fumigatus*, *Aspergillus* spp. | f-d | A | Opportunistic pathogen |
| Athlete's foot, jock itch | *Epidermophyton* spp., *Trichophyton* spp. | f-d | C-d, f | |
| Bacterial dysentery | *Shigella dysenteriae*, *Shigella* spp. | b-6γ | C,W,F-f/o | Shigellosis |
| Botulism | *Clostridium botulinum* | b-7 | F | Nearly 100% fatal food poisoning |
| Bovine spongiform encephalitis | BSE prion | pri | F | Mad cow disease |
| Chaga's disease | *Trypanosoma cruzi* | p-f | V-triatomid bug | South American sleeping sickness |
| Chickenpox | Varicella-zoster virus (Herpesviridae) | v | A; C-d | Varicella; same virus causes shingles (zoster) |
| Chlamydial urethritis and pelvic inflammatory disease | *Chlamydia trachomatis* | b-8 | S | Most common sexually transmitted disease |
| Cholera | *Vibrio cholerae* | b-6γ | W,F -f/o | Gastrointestinal |
| Cold sores | Herpes simplex type 1 virus (Herpesviridae) | v | C-d | Fever blisters |
| Common cold | Rhinoviruses (Picornaviridae), coronaviruses (Coronaviridae), adenoviruses (Adenoviridae), others | v | A; C-d,f | Rhinoviruses account for ~75% of colds, coronaviruses ~15%; adenovirus colds may be more severe |
| Cow pox | Vaccinia virus (Poxviridae) | v | C-d | Spread between cows and humans during milking; source of smallpox vaccine |
| Creutzfeldt–Jakob disease | CJD prion | pri | F | Fatal brain disease |
| Cryptosporidiosis | *Cryptosporidium parvum* | p-s | W-ing | From animal feces; infectious oocyst |
| Dengue fever | Dengue virus (Flaviviridae) | v | V-mosquito | Usually not fatal; can be a hemorrhagic fever |
| Diphtheria | *Corynebacterium diphtheriae* | b-7 | A | Respiratory disease—throat and tonsils |



**TABLE 12.3** *(Continued)*

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Ear infections (otitis media) | *Streptococcus pyogenes* | b-7 | C-d; I | Present in respiratory tract |
| | *Pseudomonas aeruginosa* | b-6γ | W-c | Swimmers' ear; opportunistic |
| Ebola hemorrhagic fever | Ebola virus (Filoviridae) | v | C-b,d,f | 90% mortality |
| Ergotism | *Claviceps purpurea* | f-a | F | Infects cereals; severe central nervous system damage if ingested |
| Food poisoning | *Bacillus cereus* | b-7 | F | Starchy foods |
| | *Clostridium perfringens* | b-7 | F | Common; meats (7–15 h after eating) |
| | *Staphylococcus aureus* | b-7 | F | Most common (1–6 h after eating) |
| Gas gangrene | *Clostridium perfringens* | b-7 | C-w | Wound infection |
| Gastroenteritis | *Campylobacter jejuni* | b-6ε | F,W-f/o | Human and animal reservoirs |
| | *Escherichia coli* O157:H7 | b-6γ | F | |
| | Norwalk virus (*Calvicindae*) | v | F,W,C-f/o | |
| | Rotaviruses (Reoviridae) | v | W | |
| | *Vibrio parahemolyticus* | b-6γ | W(F)-ing | Raw fish and shellfish |
| Infantile acute gastroenteritis | Rotaviruses (Reoviridae) | v | W | Major agent; major cause of mortality in children |
| Genital herpes | Herpes simplex type 2 virus (Herpesviridae) | v | S | Associated with cervical cancer |
| Genital warts | Papilloma virus (Papovaviridae) | v | S | Associated with cervical cancer |
| Giardiasis | *Giardia lamblia* | p-f | W-ing | From animal feces; infectious cyst |
| Gonorrhea | *Neisseria gonorrhoeae* | b-6β | S | |
| Hantavirus pulmonary syndrome | Hantavirus (Bunyaviridae) | v | A | Zoonosis—aerosolized mouse droppings |
| Hepatitis A | Hepatitis A virus (Picornaviridae) | v | W,F,C-f/o | Infectious hepatitis |
| Hepatitis B | Hepatitis B virus (Hepadnaviridae) | v | S; C-b | Serum hepatitis, liver cancer |

*(Continued)*

**TABLE 12.3** (*Continued*)

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Histoplasmosis | *Histoplasma capsulatum* | f-d | A | Respiratory disease—inhaled spores germinate in lungs |
| Impetigo | *Staphylococcus aureus*, *Streptococcus pyogenes* | b-7 | C; I | Skin sores |
| Influenza | Influenza virus (Orthomyxoviridae) | v | A | |
| Kuru | Kuru prion | pri | F | Ritualistic cannibalism |
| Legionellosis | *Legionella pneumophilia* | b-6γ | W-inh | Legionnaires' disease; milder infections called Pontiac fever |
| Leprosy | *Mycobacterium leprae* | b-7 | C; A | Hansen's disease |
| Leptospirosis | *Leptospira interrogans* | b-9 | W-c | Zoonosis—rodent, dog, or pig urine |
| Listeriosis | *Listeria monocytogenes* | b-7 | F | Agent common in soil and water |
| Lyme disease | *Borrelia burgdorferi* | b-9 | V-tick | Deer and mice are primary hosts |
| Malaria | *Plasmodium* spp. | p-s | V-mosquito | |
| Measles | Measles virus (Paramyxoviridae) | v | A; C | Rubeola |
| Meningococcal meningitis | *Neisseria meningitidis* | b-6β | A | 50% mortality without treatment |
| Mononucleosis | Mononucleosis virus (Herpesviridae) | v | C-d,f | "Kissing disease" |
| Mumps | Mumps virus (Paramyxoviridae) | v | A | Epidemic parotitis |
| Peptic ulcers | *Helicobacter pylori* | b-6ε | W?,F?,C? | *H. pylori* found in drinking water |
| Pfisteria | *Pfisteria* | a-d | W-c | Skin disease in fishermen |
| Pinkeye | *Haemophilus aegyptius* (*H. influenzae*), *Moraxella lacunata* | b-6γ | C-d,f; A | Bacterial conjunctivitis |
| Plague, bubonic | *Yersinia pestis* | b-6γ | V-flea | Zoonosis—primary hosts are rats, other rodents |
| Plague, pneumonic | *Yersinia pestis* | b-6γ | A | Form of plague in which lungs infected; highly contagious |
| Pneumonia, pneumococcal | *Streptococcus pneumoniae* | b-7 | A | |
| Pneumonia, viral | RS virus (Paramyxoviridae) | v | A | Respiratory syncytial disease |



**TABLE 12.3** (*Continued*)

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Pneumonia, walking | *Mycoplasma pneumoniae* | b-7 | A; C | Primary atypical pneumonia |
| Poison mushrooms | *Amanita* spp., others | f-b | F | Some fatal, others sickening or hallucinogenic |
| Poliomyelitis | Poliovirus (Picornaviridae) | v | W-f/o | An enterovirus; causes paralysis |
| Primary Amoebic meningoencephalitis | *Naegleria fowleri* | p-a | W-c | Swimming in warm ponds; enters through mucous membranes in mouth |
| Psittacosis | *Chlamydia psittaci* | b-8 | A | Zoonosis—birds; 20% mortality without antibiotics |
| Rabies | Rabies virus (Rhabdoviridae) | v | C-animal bite | Zoonosis—mammals |
| Rheumatic fever | *Streptococcus pyogenes* | b-7 | A | Autoimmune disease from untreated strep throat |
| Ringworm | *Epidermophyton* spp., *Trichophyton* spp. | f-d | C-d, f | |
| Rocky Mountain spotted fever | *Rickettsia rickettsii* | b-6α | V-tick | Tick-borne typhus |
| Rubella | Rubella virus (Togaviridae) | v | A; C | German measles |
| Salmonellosis | *Salmonella* spp. | b-6γ | F,W,C-f/o | Gastrointestinal disease |
| San Joaquin Valley fever | *Coccidioides immitis* | f-d | A | Coccidioidomycosis; respiratory; opportunistic |
| Scarlet fever | *Streptococcus pyogenes* | b-7 | A | Systemic disease from untreated strep throat |
| Schistosomiasis | *Schistosoma* spp. | w-t | W-c | Bilharziasis; snails are intermediate hosts |
| Smallpox | Smallpox virus (Poxviridae) | v | C-d,f; A | Variola; eradicated |
| Staph infections | *Staphylococcus aureus* | b-7 | A; C; I | |
| Strep throat | *Streptococcus pyogenes* | b-7 | A; I | Respiratory disease |
| Swimmers' itch | *Schistosoma* spp. | w-t | W-c | Zoonosis—birds; snails are intermediate hosts |
| Syphilis | *Treponema pallidum* | b-9 | S | |
| Tapeworm | *Diphyllobothrium*, *Taenia saginata*, *T. solium* | w-c | F | Fish, beef, pork |

(*Continued*)

**TABLE 12.3** *(Continued)*

| Disease | Microbial Agent | Taxa[a] | Transmission[b] | Comments |
|---|---|---|---|---|
| Tetanus | *Clostridium tetani* | b-7 | C-w | Lockjaw |
| Toxic shock syndrome | *Staphylococcus aureus* | b-7 | C; I | Most common agent |
| Toxoplasmosis | *Toxoplasma gondii* | p-s | F; C | Undercooked meat, cat feces |
| Trachoma | *Chlamydia trachomatis* | b-8 | C-d,f | Leading cause of blindness |
| Travelers' diarrhea (also see Gastroenteritis) | *Escherichia coli* (pathogenic strains) | b-6γ | W,F-f/o | |
| | Rotaviruses (Reoviridae) | v | | |
| Trichinosis | *Trichinella spiralis* | w-n | F | Mainly undercooked pork, but now rare in United States |
| Trichomoniasis | *Trichomonas vaginalis* | p-f | S | |
| Tuberculosis | *Mycobacterium tuberculosis* | b-7 | A | |
| Tularemia | *Francisella tularensis* | b-6γ | V-deer fly | Rabbit fever; zoonosis—rodents |
| Typhoid fever | *Salmonella typhi* | b-6γ | W,F-f/o | |
| Typhus fever | *Rickettsia prowazekii* | b-6α | V-louse | Epidemic typhus |
| Vaginal yeast infection | *Candida albicans* (*Monilia albicans*) | f-d | S; I | Vulvovaginitis, candidiasis, moniliasis; opportunistic |
| West Nile encephalitis | West Nile Virus (Flaviviridae) | v | V-mosquito | Zoonosis—birds |
| Whooping cough | *Bordetella pertussis* | b-6β | A | Pertussis; upper respiratory tract |
| Yaws | *Treponema pertenue* | b-9 | C-d | Produces skin sores |
| Yellow fever | Yellow Fever Virus (Flaviviridae) | v | V-mosquito | "Yellow jack"; mortality up to 50% |
| Yersiniosis | *Yersinia enterocolitica* | b-6γ | F; W? | Acute gastroenteritis |

[a] a, algae (-d, dinoflagellate); b, bacteria (- number, refers to bacterial kingdom, from Table 10.3; for Proteobacteria, Kingdom 6, class α, β, γ, δ, ε also indicated); f, fungus (-a, ascomycete; -b, basidiomycete; -d, deuteromycete); p, protozoans [-a, amoeba (Sarcodina); -f, flagellate; -s, sporozoan]; pri, prion; v, virus (family given in parentheses in preceding column after name of agent); w, worm [-c, cestode; -n, nematode (roundworm); -t, trematode (fluke)].

[b] Main routes of transmission: A, air; C, contact (-b, blood; -d, direct; -f, fomites; -w, wound); F, food; I, indigenous; S, sexual, V, vector; W, water (-c, contact; -f/o, fecal–oral route; -ing, other ingestion; -inh, inhalation

## 12.2 WATERBORNE DISEASES

The major sanitary concern with waterborne disease classically has been contamination of drinking water with fecal material, commonly from wastewater. This important **fecal-oral route** is discussed in more detail below. However, it is now recognized that several



other modes of disease transmission through water are also possible. We therefore look first more broadly at the types of water, sources of contamination, and routes of infection that can contribute to waterborne disease.

### 12.2.1 Types of Water

People may get their **potable** (drinking) water from a community source, such as a public or private water utility, or from an individual private source, such as a residential well. Water supplied to members of the public from private sources (usually, wells) by hotels, gasoline stations, camps, and similar small institutions are referred to as *noncommunity sources*. Potable water is also used for food preparation, cleaning dishes and clothes, and washing and bathing, as well as for direct ingestion. In most cases it is also used for flushing toilets and watering lawns and gardens, although in areas with limited supplies a separate nonpotable source may be used for these purposes. Industries commonly use potable water for their process water needs, sometimes following further purification. After use, much of the water from homes and industry becomes wastewater.

Other types of water that might be involved in disease transmission include recreational waters (such as rivers, lakes, and oceans) used for swimming and other water contact sports, swimming pool water, and irrigation water. Some natural waters are used for fish and shellfish harvesting. Industrial cooling waters may be from a potable source, or from ground or surface waters. Also, of course, there is precipitation (rain, snow, sleet, hail) and stormwater runoff.

### 12.2.2 Sources of Contamination

As indicated earlier, a major source of potential pathogens is human fecal material. People with gastrointestinal and some other types of infections may **shed** massive numbers of pathogens in their feces. Urine is also a potential source of contamination for some diseases. Thus, untreated or inadequately treated human wastes and sewage are a major sanitary concern.

However, there also are several other potential sources of water contamination. Water from activities such as bathing, showering, and toothbrushing, and from hand, dish, and clothes washing (often referred to as **graywater**, as opposed to the *blackwater* containing fecal material) may also contain pathogens, although typically in lower concentrations and of some different types. Urban and suburban stormwater contains fecal material and urine from pets and probably from rats, squirrels, and other wildlife. In some areas heavy concentrations of geese contribute large quantities of waste material. Agriculture may also be an important source of contamination directly from the animals being raised, or from the spreading of their manure; this may enter water through treated or untreated discharges, stormwater, or irrigation return flows (the portion of the irrigation water that flows off the field and back to a surface water, mainly to prevent salt buildup). Even in pristine areas water may not be safe to drink without treatment because of pathogens contributed by wildlife (e.g., beaver are a major reservoir of *Giardia*).

Human solid wastes may contain pathogens (e.g., from used facial tissues, diapers, and sanitary pads) that can enter water from litter, runoff, or landfill **leachate** (water that passes through the waste material in a landfill). Some industries (e.g., slaughterhouses, tanneries), institutions (e.g., hospitals), and other facilities (e.g., laboratories and doctor, dentist, and veterinary offices) are other potential sources. And especially in swimming pools, even the human body itself is a source, from skin sloughings and mouth, nose, and eye discharges.

### 12.2.3 Routes of Infection

***Ingestion*** Ingestion is the major route of infection for waterborne diseases, primarily from drinking contaminated water. However, ingestion can also occur from eating foods containing or washed with the water, or from eating fish or shellfish harvested from contaminated water (which could also be considered transmission through food). Ingestion may also occur during swimming or other water-contact activities.

Most important waterborne diseases are transmitted through the fecal–oral route, discussed in Section 12.2.4. However, some pathogens occur naturally in water. *Vibrio parahemolyticus*, for example, is a marine bacterium that cause gastroenteritis, mainly in people who eat raw fish or shellfish that have accumulated it (or in some cases, been infected by it). Other diseases, such as giardiasis and cryptosporidiosis, often appear to result from contamination by the feces of wildlife or domestic animals, although the traditional (human) fecal–oral route can also play a role.

***Contact*** It is not always necessary to ingest a waterborne pathogen for it to cause disease. For example, some bacterial eye and ear infections, such as those caused by the opportunistic pathogen *Pseudomonas aeruginosa*, can be transmitted through water in swimming pools that are overused or inadequately maintained. **Leptospirosis**, on the other hand, is caused by an obligate parasite, *Leptospira interrogans*, that is spread through contact with infected urine. The bacteria enters through mucous membranes or cuts in the skin, then attacks the kidneys and liver. It can be fatal in humans, but the main reservoirs are rodents, dogs, and pigs.

As another example, some free-living protozoans (e.g., *Naegleria*) in warm ponds can cause a fatal **primary amoebic meningoencephalitis** in swimmers. This organism also contaminated the hot springs of the famous Roman baths at Bath, England, and forced their closing for many years in the late twentieth century. The organism enters the body by penetrating the mucous membranes of the mouth and nose. (Thus, the route of exposure is not really ingestion, since the amoeba is not swallowed.)

**Schistosomiasis** is one of the most important debilitating parasitic diseases of the tropics, infecting over 200 million people. It is caused by several species of trematode flatworms of the genus *Schistosoma*. Eggs of these blood flukes are discharged in the urine and/or feces (depending on species) of the infected human. As part of their complex life cycle, the eggs hatch in water and the larva are ingested by certain aquatic snails, which then become infected and serve as the intermediate host. A distinct larval stage, the cercaria, develops, leaves the snail, and penetrates the skin of a new human host who walks through or bathes in the water. Building of dams has inadvertently led to increases in this disease by extending the range of the snails.

Fortunately, the appropriate snails do not live in the United States, so schistosomiasis does not occur here. However, related flukes do infect birds, again with snails as the intermediate host. Occasionally, one of these cercaria will inadvertently penetrate a human's skin, where it dies, unable to complete its life cycle. The resulting irritation is referred to as **swimmers' itch.**



***Inhalation*** Inhalation can be a route of exposure for a few waterborne diseases. **Legionnaires' disease**, or legionellosis, caused by *Legionella pneumophilia*, is perhaps the best known example. This bacterium grows in warm water, such as that in cooling towers, air-conditioning system evaporators, and hot-water tanks, as well as in natural aquatic habitats. If aerosols from such a system are inhaled, infection and potentially fatal pneumonia can result, especially in elderly or immunocompromised patients. (A milder infection of *L. pneumophilia* is referred to as **Pontiac fever**.) Unlike most other respiratory diseases, however, legionellosis is not spread from person to person, but rather, from aerosolized water. The first recognized outbreak resulted in 26 deaths at a 1976 convention in Philadelphia of the American Legion (hence its name). Later cases have included exposure while taking a shower.

### 12.2.4 Fecal–Oral Route

Fecal material is almost universally recognized as being unsanitary. How is it then that the fecal–oral route is such an important source of disease transmission (in food and from direct contact, as well as for water)? Part of the answer can be seen in Figure 12.3. Towns historically have been located along rivers or streams that served as their water source. Water typically is withdrawn upstream of the town and wastewater is discharged downstream. Beyond the obvious sanitary merits of this approach, it allowed both water delivery and wastewater collection to be by gravity: the water and wastewater flowing downhill. However, as areas became more densely populated, the wastewater discharge of one town soon became the water intake for the next community downstream.

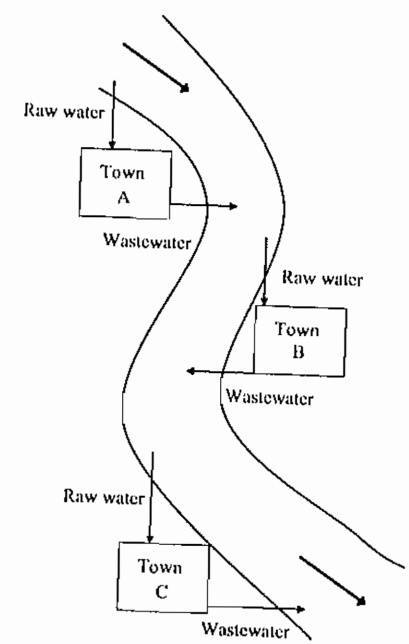


**Figure 12.3** Typical pattern of water supply and wastewater disposal.

Most diseases transmitted by the fecal–oral route (whether through water, food, or direct contact) have their primary effect on the intestines and thus are referred to as **enteric**. To understand their importance, it is helpful to look at the historical impact of two such bacterial diseases, cholera and typhoid fever.

***Cholera*** Cholera is an acute intestinal disease marked by severe diarrhea and vomiting. The bacterium responsible, *Vibrio cholerae*, reproduces in the small intestine, releasing an **enterotoxin** (a toxin affecting the intestines) that triggers the resultant stress on the victim. Bodily fluids may be depleted so rapidly that the victim dies within hours unless preventive measures are taken, such as providing intravenous replacement of fluids and salts.

Cholera was originally endemic to South Asia, but there have been seven major pandemics (the first beginning in 1817), and it is now also endemic to South and Central America and perhaps to the Gulf coast of the United States. The early U.S. epidemics (first: 1832–1834; second: 1849–1854) produced widespread fear—not surprisingly, since there was no cure for this usually fatal disease. In 1832, 20% of the population of New Orleans died of cholera, while in 1849 another 5000 people died there, along with 8000 in New York City.

In 1854, **Dr. John Snow** (Figure 12.4) performed two studies of the incidence of cholera in London. These are now recognized as the first epidemiological studies ever

**Figure 12.4** John Snow in 1857, one year before his death.



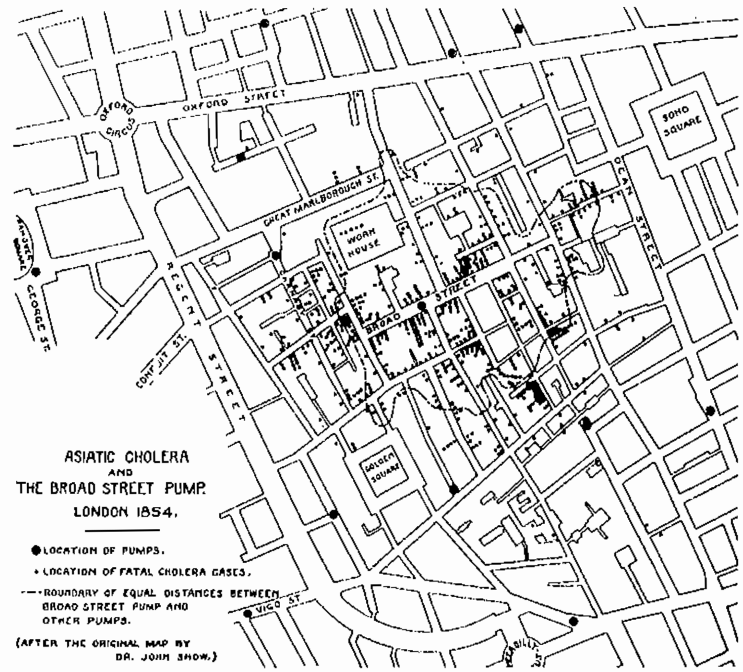


**Figure 12.5** John Snow: cholera deaths and the Broad Street pump.

conducted, predating the formalization of the germ theory of disease (Section 12.1.1). In the better known of these studies, Snow plotted on a map the residence of each person who died of cholera in one area of town served by public wells with pumps (buildings there did not have indoor plumbing). He found 521 cholera deaths within 250 yards of the **Broad Street pump** (Figure 12.5). The incidence of cholera was much higher among people living close to, and therefore presumably using water from, this pump as opposed to others located in the area. He also found evidence that this well was contaminated with sewage, and in an example of an early public health measure, had the pump handle removed (rendering it unusable)! The adjacent pub is now named in his honor (Figure 12.6).

In the second study, Snow reviewed cholera deaths in another part of London served by two competing water companies. Customers of the Southwark and Vauxhall Company had 31.5 cholera deaths per 1000 houses served, whereas the rate for the Lambeth Company was 3.7 per 1000 houses served. Both companies took their water from the Thames River and delivered it through pipelines, without treatment. However, Southwark and Vauxhall withdrew water from the river near central London, where it was contaminated with untreated sewage, whereas Lambeth's source was upstream of the city, and relatively pure.

Attempts to control cholera also figured in some of the earliest efforts at water purification as a public health measure. During the German epidemic of 1892, the adjoining cities Hamburg (upstream) and Altona (downstream) were drawing their water from the Elbe. However, Altona practiced slow sand filtration, and despite the more contaminated

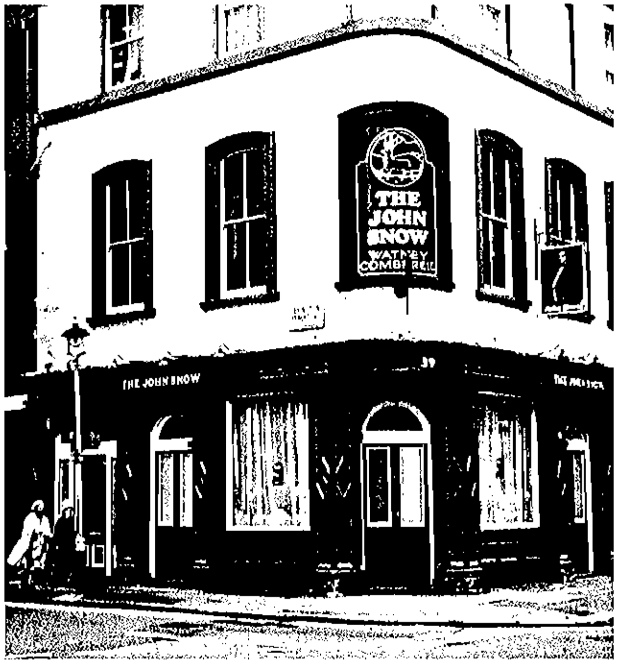


**Figure 12.6** Snow's Pub in London's Soho district, adjacent to the infamous Broad Street pump.

water source, had a cholera death rate of only 2.3 per 1000 people (many traceable to drinking Hamburg water), compared to 13.4 for Hamburg (Table 12.4).

Medical treatment traditionally involved intravenous rehydration until the disease ran its course. However, this was not available to many in poorer countries. A simpler treatment called *oral rehydration therapy* (ORT) is saving many lives around the world (see Section 9.9).

Cholera was **eradicated** (eliminated) in the United States in 1911. However, it reappeared in 1973, and there have been small numbers of cases since, mostly associated with eating shellfish harvested along the coast of the Gulf of Mexico. Worldwide, cholera still accounts for more than 120,000 deaths per year.

***Typhoid Fever*** Although typhoid fever (caused by *Salmonella typhi*) was later transmitted mainly through food in the United States, originally it was also a major waterborne disease. Although it does not have as high a mortality rate, and thus did not provoke quite the same level of fear as cholera, it probably lead to more deaths overall: 500,000 cases with 40,000 deaths in 1909, for example. Water filtration also had a beneficial effect in reducing the incidence of typhoid fever, as can be seen in Table 12.4 for the cities of Pittsburgh, Cincinnati, and Louisville.

Another water treatment technology, disinfection with chlorine, was first utilized for an urban water supply in the United States in Jersey City, New Jersey, in 1908. Some of the early beneficial effects of chlorination in controlling disease are also shown in Table 12.4.



**TABLE 12.4 Correlation between Sand Filtration (SF) or Chlorination (Chlor) of Water Supplies and Deaths from Cholera or Typhoid Fever**

| Disease | Date | City | Treatment | Deaths | Rate/100,000 |
|---|---|---|---|---|---|
| Cholera | 1892 | Hamburg, Germany[a] | None | 8606 | 1344 |
| | | Altona, Germany[a] | SF | 328 | 230 |
| Typhoid fever | 1907 | Pittsburgh, PA | None | | 125 |
| | 1908 | | SF[b] | | 49 |
| | 1902–1907 | Cincinnati, OH | None | | 57 |
| | 1908–1913 | | SF | | 11 |
| | 1904–1909 | Louisville, KT | None | | 58 |
| | 1910–1915 | | SF | | 24 |
| | 11–12/1914 | Hull, Quebec[c] | None | 200 | 1000 |
| | | Ottawa, Ontario[c] | Chlor | 28 | 28 |
| | 1917 | Wheeling, WV | None | 200 | |
| | 1918 | | None | 155 | |
| | 1–3/1919 | | Chlor[d] | 7 | |

[a]Adjoining cities; Hamburg is immediately upstream of Altona on the Elbe River.
[b]Only part of the water supply was filtered.
[c]On opposite banks of the Ottawa River, Canada.
[d]Chlorination began late in 1918.

Figure 12.7 shows the drop in typhoid in New York attributable largely to improved water treatment.

In the United States, the annual incidence of typhoid fever has dropped to about 0.2 case per 100,000 population, and the majority of these are in people who acquired the disease while abroad. However, worldwide estimates for the incidence of typhoid fever are still on the order of 16 million cases and over 600,000 deaths a year. Although animals are a major source of other *Salmonella* species, the reservoir for *S. typhi* is usually man.

***Other Fecal–Oral Route Diseases*** As indicated in Table 12.3, a number of other waterborne diseases are spread through the fecal–oral route. This includes viral diseases such as poliomyelitis (now essentially eradicated in the United States through vaccination) and

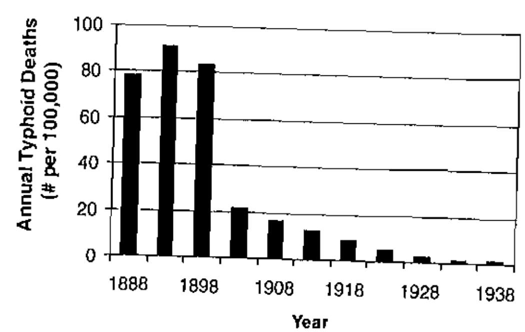


**Figure 12.7** Annual typhoid cases (per 100,000 residents) in New York, 1888–1938.

hepatitis A. In one classic case (1955), 30,000 cases of infectious hepatitis were traced to drinking water in New Delhi, India, that was properly chlorinated but which had excess turbidity. It is believed that the viruses within the particulate material were protected from the chlorine. Waterborne viruses (especially rotaviruses) are also responsible for a portion of travelers' diarrhea, and contribute to the over 3 million yearly death toll worldwide from diarrheal diseases, mostly among young children (infantile acute gastroenteritis).

Other important bacterial enteric diseases include **salmonellosis** (caused by *Salmonella* species other than *S. typhi*) and bacterial dysentery, or **shigellosis** (caused by *Shigella* spp.). Salmonellosis is also easily spread through food, and *Shigella* by the fecal–oral route through direct contact, especially in settings such as child-care centers.

**Amebiasis**, or **amoebic dysentery**, is caused by the protozoan *Entamoeba histolytica*. This is the third most prevalent parasitic disease worldwide (after schistosomiasis and malaria) and has the eleventh highest annual mortality (100,000) among all infectious diseases. The infectious stage is a cyst.

***Breaking the Chain*** In most developed countries, waterborne disease from the fecal–oral route has been greatly reduced. Public health practices in such countries have been successful in breaking the chain of disease and its transmission. Through proper sewage treatment and waste disposal, fecal contamination of water has decreased dramatically. Water purification techniques, in turn, have been successful in virtually eliminating pathogens from drinking water. As a result, there are relatively few infected persons in the population who are shedding pathogens into the wastewater. This smaller reservoir further helps prevent disease transmission even when there are lapses in wastewater or potable water treatment. Quickly locating the source of an outbreak and treating infected persons further help minimize the spread of disease. Safe potable water also makes hand washing easier and more effective, reducing fecal–oral transmission through food and direct contact.

### 12.2.5 Modern and Recent Outbreaks

Table 12.5 shows the 108 known outbreaks of waterborne disease in the United States for 1993–2000. The six organisms responsible for more than one outbreak were the protozoans *Cryptosporidium parvum* and *Giardia* spp. and the bacteria *Salmonella* spp., *Shigella* spp., *Escherichia coli* type O157:H7 (Section 12.3.2), and *Campylobacter jejuni*. There were also two viruses. All produce gastrointestinal illness, and all but *Salmonella* and *Shigella* are relatively newly recognized as causes of waterborne disease. Many of the AGI (acute gastrointestinal illness from an unknown agent) cases are probably from viruses, although one was chemical.

***Cryptosporidiosis and Giardiasis*** The very large number of cases of cryptosporidiosis in the table results from a single major outbreak in Milwaukee, Wisconsin, in which 403,000 people were infected, with 4400 hospitalized and 100 fatalities. Worldwide it is estimated that there may be 500 million cases per year. A major outbreak of both cryptosporidiosis and giardiasis also occurred in Sydney, Australia, in 1999, threatening the Summer Olympics held there the following year. Both protozoans form resistant resting stages (oocysts for *Cryptosporidium*, cysts for *Giardia*) that are highly resistant to disinfection. This has led to a requirement in the United States for filtration of all community water systems that utilize surface water sources.

**TABLE 12.5 Disease Outbreaks in the United States Associated with Drinking Water, 1993–2000**[a]

| | Type of Water System | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Community | | Noncommunity | | Individual | | Total | | Percentages | | |
| Etiologic Agent | Outbreaks | Cases | Outbreaks | Cases | Outbreaks | Cases | Outbreaks | Cases | Outbreaks | Cases[c] | Cases[d] |
| *Giardia* spp. | 8 | 1,891 | 3 | 139 | 6 | 25 | 17 | 2,055 | 15.7 | 0.50 | 23.3 |
| *Cryptosporidium parvum* | 5 | 404,642 | 1 | 27 | 2 | 39 | 8 | 404,708 | 7.4 | 98.22 | 16.7 |
| *Shigella* spp. | 1 | 83 | 3 | 323 | 1 | 33 | 5 | 439 | 4.6 | 0.11 | 5.0 |
| *Escherichia coli* O157:H7 | 3 | 208 | 2 | 37 | 3 | 12 | 8 | 257 | 7.4 | 0.06 | 2.9 |
| *Campylobacter jejuni* | 1 | 172 | 3 | 66 | 1 | 102 | 5 | 340 | 4.6 | 0.08 | 3.9 |
| *E. coli* O157:H7/*C. jejuni* | 0 | 0 | 1 | 781 | 0 | 0 | 1 | 781 | 0.9 | 0.19 | 8.9 |
| *Salmonella* spp. | 2 | 749 | 0 | 0 | 1 | 84 | 3 | 833 | 2.8 | 0.20 | 9.5 |
| Non-O1 *Vibrio cholerae* | 1 | 11 | 0 | 0 | 0 | 0 | 1 | 11 | 0.9 | 0.00 | 0.1 |
| *Plesiomonas shigelloides* | 0 | 0 | 1 | 60 | 0 | 0 | 1 | 60 | 0.9 | 0.01 | 0.7 |
| Norwalk-like viruses | 0 | 0 | 3 | 356 | 0 | 0 | 3 | 356 | 2.8 | 0.09 | 4.0 |
| Small round-structured Virus | 1 | 148 | 1 | 70 | 0 | 0 | 2 | 218 | 1.9 | 0.05 | 2.5 |
| AGI[b] | 8 | 85 | 17 | 1,465 | 10 | 208 | 35 | 1,758 | 32.4 | 0.43 | 20.0 |
| Chemical | 13 | 215 | 0 | 0 | 6 | 8 | 19 | 223 | 17.6 | 0.05 | 2.5 |
| Total | 43 | 408,204 | 35 | 3,324 | 30 | 511 | 108 | 412,039 | 100.0 | 100.0 | 100.0 |
| Percentage[c] | 39.8 | 99.1 | 32.4 | 0.8 | 27.8 | 0.12 | 100.0 | 100.0 | | | |
| Percentage[d] | | 56.4 | | 37.8 | | 5.8 | | 100.0 | | | |

[a]Compiled from data available on the Centers for Disease Control Web site; $n = 108$.
[b]AGI, acute gastrointestinal illness of unknown etiology.
[c]Percentage based on all 108 outbreaks or 412,039 cases.
[d]Percentage based on 8802 cases, excluding the Milwaukee outbreak of *Cryptosporidium* infecting 403,237.

**TABLE 12.6 Drinking Water System Deficiencies Associated with Waterborne Disease Outbreaks in the United States, 1993–2000**[a]

| | Type of Water System | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Community | | Noncommunity | | Individual | | Total | |
| Type of Deficiency | No. | % | No. | % | No. | % | No. | % |
| Untreated surface water | 0 | 0.0 | 0 | 0.0 | 2 | 6.7 | 2 | 1.9 |
| Untreated groundwater | 5 | 11.6 | 17 | 48.6 | 14 | 46.7 | 36 | 33.3 |
| Treatment | 16 | 37.2 | 13 | 37.1 | 2 | 6.7 | 31 | 28.7 |
| Distribution system | 18 | 41.9 | 4 | 11.4 | 4 | 13.3 | 26 | 24.1 |
| Unknown | 4 | 9.3 | 1 | 2.9 | 8 | 26.7 | 13 | 12.0 |
| Total | 43 | 100.0 | 35 | 100.0 | 30 | 100.0 | 108 | 100.0 |

[a]Compiled from data available on the U.S. Centers for Disease Control Web site; $n = 108$.

***Campylobacter*** The first reported outbreak of waterborne gastroenteritis in the United States involving *C. jejuni* was in 1978, in Bennington, Vermont. Of a total population of 10,000 using the community water supply, 2000 became ill. *Campylobacter* (both *C. jejuni* and *C. fetus*) can also be spread by food, especially chicken and turkey (which are reservoirs).

***System Deficiency*** Table 12.6 indicates the breakdown of incidents by the type of deficiency in the potable water system. For community systems, the outbreaks are almost evenly divided between treatment and distribution problems, whereas for noncommunity and individual systems, consuming untreated water was the primary known cause.

## 12.3 FOODBORNE DISEASES

There are many diseases that can be caused by the consumption of contaminated foods. The responsible microbial agent may have been present in the original material (e.g., growth of *Salmonella* in chickens), or been introduced at some point during subsequent handling and preparation steps as a result of improper sanitation. In most instances, these problems can be linked to improper cooking or storage, particularly of foods containing meat, milk, eggs, cheese, poultry, fish, and shellfish. Table 12.7 provides an approximate percentile breakdown of various bacterial foodborne diseases in the United States by their causative agent and indicates the food products with which they are typically associated.

The sanitary aspects of commercial food distribution and handling within the United States have long been carefully regulated, but there are still serious lapses. Additionally, many foods are now being imported from countries around the world with far less stringent standards. However, most cases are associated with poor practices in homes, institutions (e.g., nursing homes), or small restaurants.

Foodborne diseases of microbial origin may be split into two categories. **Food poisoning** results from ingestion of preformed microbial toxins. In some cases, the microorganism itself may no longer be viable or may be incapable of infecting a human host, but the products of its previous activity result in disease. **Food-transmitted infection**, on the other hand (although sometimes also called food poisoning by the public), results when the causative organism is transmitted via food, then parasitizes the new host to produce disease. Some of the diseases of concern are discussed briefly below. Note that the specific symptoms, particularly the time to their onset, may help distinguish the particular agent.