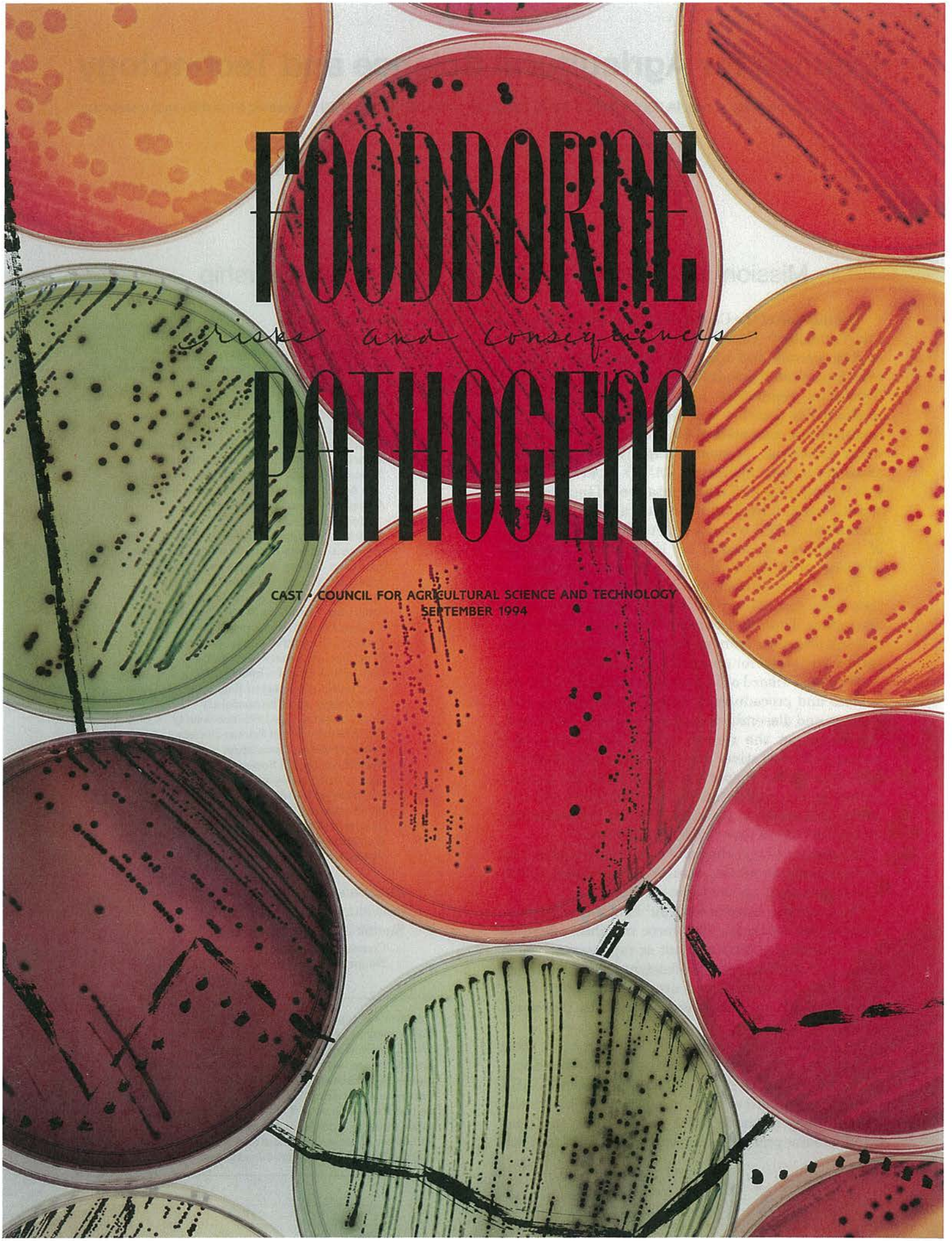

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Council for Agricultural Science and Technology

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The mission of the Council for Agricultural Science and Technology (CAST) is to identify food and fiber, environmental, and other agricultural issues and to interpret related scientific research information for legislators, regulators, and the media involved in public policy decision making. CAST is a nonprofit organization composed of 30 scientific societies and many individual, student, company, nonprofit, and associate society members. CAST's Board of Directors is composed of 47 representatives of the scientific societies and individual members, and an Executive Committee. CAST was established in 1972 as a result of a meeting sponsored in 1970 by the National Academy of Sciences, National Research Council.

The primary mission of CAST is the publication of task force reports written by scientists from many disciplines. The CAST National Concerns Committee screens proposals from all sources and recommends to the board topics for approval as publication projects.

The CAST Board of Directors is responsible for the policies and procedures followed in developing, processing, and disseminating the documents produced. Depending on the nature of the publication, the society representatives may nominate qualified persons from their respective disciplines for participation on the task force. Aside from these involvements, the member societies have no responsibility for the content of any CAST publication.

Diverse writing groups and active participation by all task force members assures readers that a balanced statement on the topic will result.

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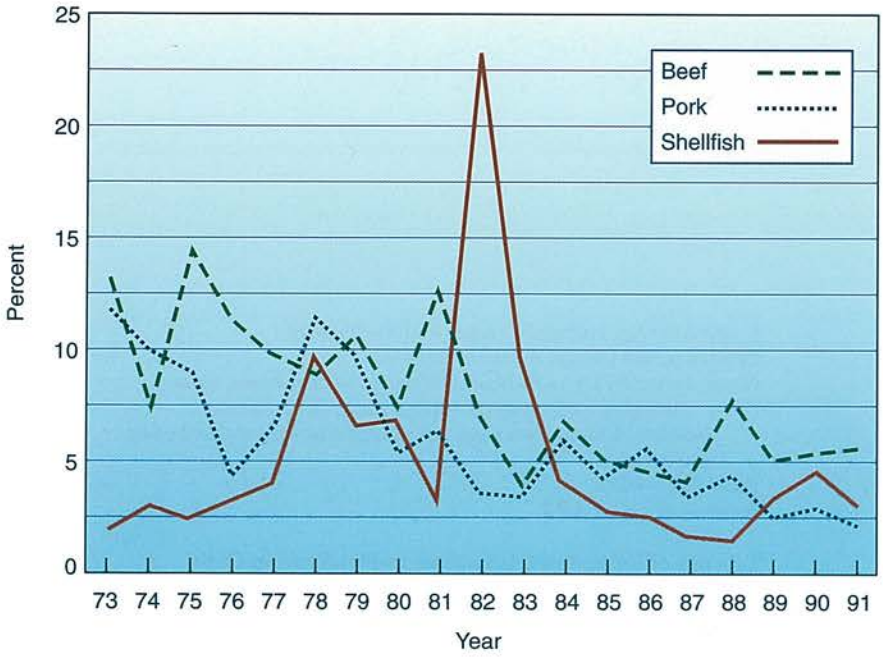

Figure C.1. **Abstract cover graph (adapted from Bean and Griffin, 1990; Bean, pers. com., 1994). Percentage of foodborne disease outbreaks with known vehicle associated with beef, pork, and shellfish, by year, 1973–1991. Variation in vehicles for foodborne pathogens over time is caused by several factors, which include**

- **random fluctuations in pathogen detection because only a fraction of all outbreaks are reported,**
- **improvement in test sensitivity and epidemiology that enables new foodborne pathogens to be identified or increases the probability of pathogen detections,**
- **changes in production, processing, marketing, and consumption practices that alter human exposure over time,**
- **evolutionary changes in pathogens and alteration in their econiches causing different foods to become pathogen vehicles at different times, and**
- **regulatory actions successful in controlling pathogens and reducing the incidence from particular food sources.**

See Bean and Griffin (1990) for more detail about annual variations in pathogen-food relationships. The 1988–1991 data was provided by Dr. Nancy H. Bean, Centers for Disease Control and Prevention, Atlanta, Georgia.

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Contents

Figures

Tables

Foreword

Following a recommendation by the CAST National Concerns Committee, the CAST Board of Directors authorized preparation of a report addressing risks associated with foodborne pathogens.

Dr. Peggy F. Foegeding, professor, Department of Food Science, North Carolina State University, Raleigh, and Dr. Tanya Roberts, Economic Research Service, U.S. Department of Agriculture, served as cochairs of the task force. A highly qualified group of scientists was chosen to serve as authors and includes persons with expertise in economics, epidemiology, food safety, food science, infectious diseases, the law, medicine, microbiology, and public health.

The authors met and prepared an initial draft of the report. A meeting of a subcommittee of the task force and scientists at the Centers for Disease Control and Prevention in Atlanta, Georgia resulted in additional data being included in the report. A meeting of authors attending the Institute of Food Technologists' annual meeting in Atlanta, Georgia in June 1994 was held to discuss the final draft. All authors assisted in revising all drafts and reviewing the proofs. The CAST Executive and Editorial Review committees reviewed the final draft. The CAST staff provided editorial and structural suggestions and published the report. The chairs and authors are responsible for all scientific content in the report.

On behalf of CAST, we thank the authors who gave of their time and expertise to prepare this report as a contribution of the scientific community to public understanding of the issues. Also, we thank the employers of the authors who made the time of these individuals available at no cost to CAST. The members of CAST deserve special recognition because the unrestricted contributions they have made in support of the work of CAST have financed the preparation and publication of this report.

This report is being distributed to members of Congress, the U.S. Department of Agriculture, the Food Safety Inspection Service, the Centers for Disease Control and Prevention, the Congressional Research Service, the Food and Drug Administration, the Environmental Protection Agency, the Agency for International Development, Office of Technology Assessment, Office of Management and Budget, media personnel, and to institutional members of CAST. Individual members of CAST may receive a complimentary copy upon request for a $3.00 postage and handling charge.

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Kayleen A. Niyo
Scientific Editor

Interpretive Summary

The Council for Agricultural Science and Technology (CAST) created a task force to determine the state of knowledge about U.S. foodborne disease risks.

Task Force Findings

- A comprehensive system of assessing the risks of human illness from microbial pathogens in the food supply has yet to be devised. Although the microbial foodborne disease burden of the United States is not known with accuracy, estimates from the literature indicate and the general consensus of CAST task force members is that cases likely range from 6.5 million to 33 million annually and that deaths may be as high as 9,000 annually.
- Although foods of animal origin most often are identified as the vehicles of foodborne disease outbreaks reported to the Centers for Disease Control and Prevention (CDC), a wide variety of foods are associated with foodborne illness.
- No agreed-upon method for setting food safety priorities exists.
- It is difficult to use available statistics, which are based on all routes (including nonfoodborne) of infection or intoxication, to identify the foodborne component of total human illness.
- Control methods affect specific pathogens and toxins differently; no one method will eliminate all pathogens and their toxins from the food chain. Pathogens or their toxins may be controlled by preventing their entry into the food, by reducing the amount present, or by destroying that which is present.
- Application of hazard analysis critical control point (HACCP) systems can reduce the likelihood of foodborne illness. The efficacy of a HACCP system depends on the rigor and consistency with which it is designed and implemented and the use of (a) critical control point(s) that will control pathogens.

Recommendations for Reducing Foodborne Illness

1. **We recommend that food safety policy be based on risk assessment** using all available data for acute and chronic foodborne disease.
2. **We recommend that the food safety information database be expanded** to provide more complete information on the incidence of foodborne disease by pathogen and by food.
3. Recognizing that advances in knowledge of foodborne disease prevention and control are essential to advancing food safety, **we recommend that vigorous fundamental and applied research efforts related to food safety be encouraged and supported.**
4. **We recommend that new rapid, reliable, sensitive, and economical methods continue to be developed to allow fast and accurate detection of hazardous organisms and their toxins.**
5. **We recommend that continued rigorous epidemiological studies be conducted to assist in establishing the cause of illness and effect of the occurrence of a particular pathogen or toxin.**
6. We acknowledge that both **dose response and minimum infective or intoxicating dose** are difficult types of data to accumulate yet **we recommend that**, to the extent possible, **these data and doses be determined or estimated.**
7. **We recommend that estimates of (a) numbers of acute illnesses, chronic illnesses, and deaths; (b) costs of foodborne diseases; (c) severity of illnesses; and (d) duration of chronic illnesses be improved.**
8. **We recommend that research be conducted on the mechanisms of chronic illnesses** with which foodborne pathogens are associated, so that appropriately targeted detection and control strategies can be developed.
9. **We recommend that research be conducted to identify foods likely to be associated with specific pathogens or toxins, and to estab-**

lish risk minimization controls. Whether new processing methods create an environmental niche for pathogens should be determined.

10. **We recommend that populations at high risk for opportunistic pathogens causing acute or chronic illnesses be identified and that special control programs be tailored to inform these populations of their high-risk status** so that they can protect themselves.
11. **We recommend that consumers be allowed choices in the types of food available** to them yet be made aware of their relative risk status, including their risks of acute as well as chronic illnesses.
12. **We recommend that federal food safety regulations be modified to reflect that zero risk of foodborne illness is not possible.**
13. **We recommend that food safety goals and priorities be set so that resources may be allocated and targeted appropriately.**
14. **We recommend that control practices be applied from food source to consumption**, including the incorporation of HACCP principles. New scientific advances should be incorporated into control practices.
15. Given that risk communication is critical because zero risk is impossible, **we recommend that the public be well educated regarding safe food handling and the relative and changing risk status of individuals.**

Summary

Charge to the Task Force

In 1983, the National Research Council (NRC) recommended that risk assessment procedures be applied to strengthen the scientific basis of risk decisions within the government. Risk assessment, risk management, and risk communication are the three components of risk analysis. In 1985, the NRC recommended that microbial pathogen risk assessment be the foundation for the nation's meat and poultry inspection system. In 1989, the Council for Agricultural Science and Technology (CAST) created a task force to determine the state of knowledge about U.S. foodborne disease risks. Recently several groups have emphasized the need for foodborne disease risk assessment, and improvements based on a risk assessment approach have been proposed (Bromley, 1993; Hathaway, 1994; U.S. General Accounting Office, 1992).

The CAST task force framed the issue by addressing the following questions:

- What types of human health risks are associated with microbial pathogens in food?
- What foods harbor these pathogens and are the causes of human disease?
- How many acute microbial foodborne illnesses and deaths occur annually?
- How many chronic human illnesses and deaths are caused by foodborne pathogens?
- What are the economic costs of these foodborne diseases annually?
- Are risk assessment databases adequate or are improvements needed to reduce uncertainty about the incidence of acute and chronic foodborne diseases?
- What preventive actions will reduce the incidence and severity of microbial foodborne disease?

Task Force Findings

1. A comprehensive system of assessing the risks of human illness from microbial pathogens in the food supply has yet to be devised.
   - The Centers for Disease Control and Prevention's (CDC) foodborne surveillance system is limited by the data it receives from state departments of health and other sources and thus reports only a fraction of foodborne disease outbreaks.
   - In 1994, the Council of State and Territorial Epidemiologists pointed out that final decisions regarding foodborne disease surveillance are made by each state and that 12 states have no surveillance staff assigned to monitor food related or waterborne pathogens; thus, outbreaks are unlikely to be reported from these states.
   - The last systematic CDC study to estimate the actual incidence of foodborne bacterial, viral, and parasitic infections was conducted in 1983 and relied greatly on expert judgment (Bennett et al., 1987; Voelker, 1994). A new study is needed urgently.
   - Trends in the CDC's reported foodborne outbreaks may not reflect changes in actual cases accurately. New pathogens always are underreported because testing procedures are nonstandardized or have not been developed, or because doctors tend to request tests for familiar pathogens. For *Campylobacter jejuni*, the causes of reported outbreak cases and of sporadic cases not reported but detected by special investigations differ. Similar differences may exist for other pathogens.
   - For some illnesses, it may take thousands of cases for an outbreak causing diarrheal illness randomly in a large urban area to be detected by public health authorities (Berkelman et al., 1994).
   - Any assessment based solely on currently known pathogens and disease syndromes likely is incomplete. New etiologies continue to be added as the science base expands, but nearly half of the recorded outbreaks and cases still are of unknown etiology (Bean et al., 1990a, 1990b).

Although the microbial foodborne disease burden of the United States is not known with accuracy, estimates from the literature indicate and the general consensus of CAST task force members is that cases likely range from 6.5 million to 33 million annually and that deaths may be as high as 9,000 annually (the CDC estimates that there are 9,000 microbial foodborne deaths annually).

2. Although foods of animal origin most often are identified as the vehicles of foodborne disease outbreaks reported to the CDC, a wide variety of foods are associated with foodborne illness (Bean et al., 1990a, 1990b).
3. No agreed-upon method for setting food safety priorities exists. The U.S. Health and Human Service's *Healthy People 2000* report used, without a clear definition, both case number and severity to set targets for *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella enteritidis* (U.S. Department of Health and Human Services, 1991).
4. It is difficult to use available statistics, which are based on all routes (including nonfoodborne) of infection or intoxication, to identify the foodborne component of total human illness.
5. Pathogens and their toxins can enter the food chain at any point from the farm to the kitchen. Pathogens or toxins may be present on raw foodstuffs or may be introduced into the food by contamination in the postharvest environment, e.g., by processing plant workers or by foodhandlers. The ability to survive, to grow, and to produce toxin and the persistence of active toxins are consequences of organism, environment, and treatment process. Thus, methods to prevent or to control pathogens differ and may involve excluding contaminated feed and food ingredients, practicing good sanitation, refrigerating, cooking, or irradiating. Control methods affect specific pathogens and toxins differently; no one method will eliminate all pathogens and their toxins from the food chain. Pathogens or their toxins may be controlled by preventing their entry into the food, by reducing the amount present, or by destroying that which is present.
6. Application of hazard analysis critical control point (HACCP) systems can reduce the likelihood of foodborne illness. Control systems must recognize the diversity and the variability of pathogens, the vagaries of detection, and the wide range of control options. The cost and efficacy of HACCP systems differ considerably, and creative solutions may be pathogen-specific. In each instance, the efficacy of a HACCP system depends on the rigor and consistency with which it is designed and implemented and the use of (a) critical control point(s) that will control pathogens.

Task Force Recommendations

The task force acknowledges that zero risk of foodborne illness is neither possible nor practical. We offer the following recommendations for reducing foodborne illness.

1. **We recommend that food safety policy be based on risk assessment** using all available data for acute and chronic foodborne disease.
2. **We recommend that the food safety information database be expanded** to provide more complete information on the incidence of foodborne disease by pathogen and by food risk assessment use. The database should be accessible through a computer network to all potential users (public health officials, regulatory authorities, food companies, food safety scientists, and others). The CDC should take the lead in creating the new database with input from the Food Safety Inspection Service (FSIS); the U.S. Food and Drug Administration (FDA); state departments of health; and other individuals or organizations, e.g., the database should include consumer illness complaints and survey data. This integrated database would allow identification of the points at which pathogens occur in the food chain and would facilitate identification of pathogen control points, estimation of control option costs, and tracking of intervention success in terms of reduced human illness and death.
3. Recognizing that advances in knowledge of foodborne disease prevention and control are essential to advancing food safety, **we recommend that vigorous fundamental and applied research efforts related to food safety be encouraged and supported.** Research on the biology and the ecology of pathogens is especially important in areas such as microbial ecology of pathogenic bacteria and viruses; genetic transfer of virulence determinants; mechanisms of virulence; potential of growth conditions to enhance virulence; sensitivities of pathogens and toxins to control procedures; activities and responses of organisms in natural environments, e.g., biofilms in processing facilities; and applications of current technologies for tracking organisms in the

environment and in epidemiological investigations.

4. **We recommend that new rapid, reliable, sensitive, and economical methods continue to be developed to allow fast and accurate detection of hazardous organisms and their toxins.** This objective is especially important for detection of viruses in food, environmental, and fecal samples because viral detection methods are inadequate.
5. We acknowledge that epidemiological studies to link incidence of a foodborne pathogen to illness will be increasingly important as detection method sensitivity for pathogens or for their toxins increases. Therefore, **we recommend continued rigorous epidemiological studies to assist in establishing cause of illness and effect of the occurrence of a particular pathogen or toxin.**
6. We acknowledge that both **dose response and minimum infective or intoxicating dose** are difficult types of data to accumulate (because the use of human volunteers is unacceptable) yet **we recommend that**, to the extent possible, **these data and doses be determined or estimates be improved** using data from well-documented outbreaks.
7. **We recommend that estimates of (a) numbers of acute illnesses, chronic illnesses, and deaths; (b) costs of foodborne diseases; (c) severity of illnesses; and (d) duration of chronic illnesses be improved.**
8. **We recommend that research be conducted on the mechanisms of chronic illnesses** with which foodborne pathogens are associated, so that appropriately targeted detection and control strategies can be developed.
9. **We recommend that research be conducted to identify foods likely to be associated with specific pathogens or toxins**, i.e., high-risk foods such as raw foods of animal origin, **and to establish risk minimization controls**. Whether new processing methods create an environmental niche for pathogens should be determined.
10. **We recommend that populations at high risk for opportunistic pathogens causing acute or chronic illnesses be identified and that special control programs be tailored to inform these populations of their high-risk status** so that they can protect themselves. An interactive computer database could be established on Internet to list foods likely to harbor the pathogen of interest, to improve understanding of the safest handling and preparation procedures for specific foods, and to help high-risk populations select optimal food/safety combinations. These populations may include persons with low stomach acidity, high-iron blood level, or diabetes; alcoholics; children; pregnant women; adults over 50 or 60; those with organ transplants, cancer, or acquired immunodeficiency disease syndrome (AIDS); or others. Educational strategies must acknowledge that the risk status of individuals is not constant.
11. **We recommend that consumers be allowed choices in the types of food available** to them yet be made aware of their relative risk status, including their risks of acute as well as chronic illnesses. It should not be required that all foods be safe for consumption by high-risk consumers; this would greatly limit food choices, e.g., to canned or irradiated food, excluding fresh meat, poultry, and seafood. Special federal programs could be established to certify the safety of specific operations to produce foods for high-risk individuals; these foods probably would be priced higher.
12. **We recommend that federal food safety regulations and policies be modified to reflect that zero risk of foodborne illness is not possible.** This change will allow honest and effective risk management.
13. **We recommend that food safety goals and priorities be set so that resources may be allocated and targeted appropriately.** Public discussion and understanding of the costs and effectiveness of control measures will be requisite.
14. **We recommend that control practices be applied from food source to consumption**, including the incorporation of HACCP principles from the farm or other source through consumption. The HACCP systems provide a systematic process-control approach focusing on food safety. Development of new procedures to control foodborne illness agents, as well as understanding of existing control steps and control procedure costs, should be encouraged so that proper and effective application is ensured. Controls for each food pathogen combination should be evaluated separately. New scientific advances should be incorporated into control practices.
15. Given that risk communication is critical because zero risk is impossible, **we recommend that the public be well educated regarding safe food handling and the relative and changing risk**

status of individuals. Education is essential if consumers are to protect their own health and to recognize the political and regulatory complexities of the issue so that they can participate in setting food safety goals. From grades K–12, science education should be strong and education concerning the hazards of foodborne diseases, their causes, and their means of prevention should be integrated into health and science curricula. Health agency personnel and university outreach programs should inform consumers about populations at risk for foodborne illness, the relative safety of various food choices, safe food handling procedures, appropriate control strategies, and the relative effectiveness of controls.

1 Introduction

The report attempts to estimate the impact of foodborne illnesses in the United States and to recommend strategies for their control.

Introduction

Foodborne pathogens, or microorganisms causing illness through ingestion of food, have been identified regularly since the mid-nineteenth century as being foodborne (Table 1.1). During this time, food-handling and -preparation practices in the United States have been changing, primarily toward convenience and therefore advance preparation. And the variety of foods available, including imported foods, has grown. Thus, the chances of contamination and abuse of foods have increased because (1) handling has increased, (2) time for abuse and possible growth of pathogens in food has been extended, and (3) expanded variety can lead to confusion about safe and appropriate handling practices. Consumers were concerned with low levels of chemical residues in foods as the most alarming food safety issue; however, they are beginning to agree with scientists that the presence of pathogens in food is the most important concern.

The objective of this report is to estimate risk and consequence of human illness from microorganisms contaminating food in the United States and to explain the complexities resulting in specific risks for populations and individuals. *Risk* is defined as the probability of the occurrence of a hazard. The report will follow the risk assessment approach of the National Academy of Sciences (NAS) (National Research Council, 1983) and will identify food-processing and -preparation practices that have improved or could improve food safety.

Risk Assessment

The NAS has convened numerous groups to address food safety. The 1969 book *An Evaluation of the Salmonella Problem* was a thorough analysis of the causes and the means of preventing salmonellosis, the most common foodborne illness known at that

Table 1.1. Decades in which selected microbiological agents were recognized as causing foodborne disease[a]

Decade	Microbiological agent
1830-1840	*Trichinella spiralis*
1850–1860	*Taenia solium, Taenia saginata*
1880–1890	*Salmonella, Staphylococcus aureus, Vibrio cholerae*
1891–1900	*Clostridium botulinum* nonproteolytic type B
1901–1910	*Streptococcus pyogenes* (Group A)
1911–1920	*Clostridium botulinum* types A and proteolytic B, poliomyelitis virus
1921–1930	*Salmonella typhi, Shigella, Streptococcus* group D[b]
1931–1940	*Clostridium botulinum* type E
1941–1950	*Clostridium perfringens, Pseudomonas aeruginosa*[b], *Vibrio parahaemolyticus*, hepatitis A virus
1951–1960	*Bacillus cereus* (diarrheal type), *Listeria monocytogenes*
1961–1970	Enteropathogenic *Escherichia coli, Plesiomonas*[b]
1971–1980	*Bacillus cereus* (emetic type), *Campylobacter*, enteroinvasive *E. coli*, Norwalk-like viruses, *Yersinia enterocolitica*
1981–1990	*Aeromonas* spp.[b], enterohemorrhagic *E. coli* (O157:H7), *Vibrio vulnificus*

[a]There often was a delay of many decades between discovery of a pathogen and routine testing for it or its toxins in foods.
[b]Conclusive link with foodborne disease has not been demonstrated.

time in the United States (National Research Council, Committee on *Salmonella*, 1969). In 1983, a seminal report on how federal programs should evaluate and control risk was published—*Risk Assessment in the Federal Government: Managing the Process* (National Research Council, 1983), which became the guiding document for a series of studies on the risk of foodborne illness. *Meat and Poultry Inspection: The Scientific Basis of the Nation's Program* (National Research Council, 1985) and *Poultry Inspection: The Basis for a Risk-Assessment System* (National Research Council, 1987) are the most relevant to this Council for Agricultural Science and Technology (CAST) report. Other NAS committees have examined the Streamlined Inspection System (SIS) proposed by the U.S. Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS) for beef inspection, the seafood inspection options, and the toxicological risk from food consumption (National Research Council, 1990, 1991, 1993).

Recently, several groups have added their support and have called for increased use of foodborne disease risk assessment:

- The White House's Federal Coordinating Council for Science, Engineering and Technology on food-safety research recommended "improvement in risk assessment methods for acute and chronic health effects caused by chemical and microbiological contaminants to determine the most serious, frequent, and costly public health problems" stemming from unsafe food (Bromley, 1993).
- The Institute of Food Technologists listed as its first priority for food-safety research the determination of "the true incidence, causes, and financial and personal impact of foodborne diseases in the U.S."
- The U.S. General Accounting Office (1992) in its report *Food Safety and Quality: Uniform, Risk-Based Inspection Needed to Ensure Safe Food Supply* stated that risk assessment is "an essential principle of an efficient and effective inspection program necessary for protecting public health."
- The joint U.S. Department of Agriculture/Food and Drug Administration/National Marine Fisheries Services National Advisory Committee on Microbiological Criteria for Foods created a risk-assessment subcommittee in 1993.
- The United Kingdom's Department of Health is launching a £2 million nationwide survey of more than 20,000 people to determine incidence, severity, microbial causes, risk factors, and costs of intestinal infectious disease.
- "Risk analysis will be of increasing importance . . . as a means of facilitating the distribution of both preharvest and postharvest inspection resources proportional to the likelihood of public health and animal health hazards, establishing internationally harmonized standards and specifications that are consistent and science-based, and improving the safety and wholesomeness of meat and meat products in local and international trade" (Hathaway, 1994).
- The Codex Alimentarius Commission has asked its committees to describe their use of risk assessment, and the Codex's meat hygiene codes of practice are under revision to incorporate "general principles for a risk analysis approach" (Hathaway, 1994).

The NAS risk assessment methodology for foodborne microbes consists of four steps (National Research Council, 1983).

1. Disease characterization/hazard identification: determining whether a chemical, microorganism, or other substance is linked causally through food consumption to human health. Pathogens can enter the food chain at many points from farm or sea to consumer. Depending on the food, organism, and processing or handling conditions, they may survive, grow, or die.
2. Dose-response assessment: determining the relationship between the magnitude of exposure and the probability of occurrence of the spectrum of possible health effects. Infective or toxic doses necessary to cause illness from various pathogens differ greatly. Ingestion of greater numbers of microorganisms or concentrations of toxins may result in shorter incubation time and/or more serious disease. Type and amount of food in which the disease agent is consumed may influence the infective or toxic dose. People differ greatly in their susceptibilities as a result of genetics, age, medication taken, stomach acidity, immune status, and health status.
3. Exposure assessment: determining the extent of human exposure before or after application of regulatory or voluntary controls. Exposure will differ (a) by types of foods likely to contain certain pathogens; (b) by region of the country (climate affects growth and/or survival of microorganisms, and both climate and population affect likelihood of human contact); (c) by trading patterns; and

(d) by animal husbandry, food-processing, -preparation, and -consumption practices.

4. Risk characterization: quantifying cases and case severity, and identifying economic and social impacts of human risk (a) by estimating the costs associated with the impact on selected populations, regions, and industries; and (b) by assessing the willingness to pay for risk reduction.

This report is organized into seven chapters, and follows the above four-step risk assessment approach. Chapter 2 describes foodborne illnesses and their causative agents. Chapter 3 details infective and toxic doses, individual response differences to etiological agents, and ranges in the severity of foodborne illnesses. Chapter 4 provides data on types and numbers of microorganisms possibly occurring in foods. Chapter 5 estimates risk of foodborne illness from known and estimated numbers of cases associated with foodborne disease and indicates the shortcomings of the available information. Chapter 6 discusses estimated economic costs of foodborne illnesses; Chapter 7 concludes this approach with current and future food handling practices that can decrease risk of foodborne illness.

Although the four-step risk assessment approach sounds simple, in practice it is quite complex. To make linkages between food and human illness, tests to identify the causative pathogen must be conducted. Yet tests may not have been developed; or their reliability, speed, or cost may limit their usefulness. Additionally, issues of sample size and of nonhomogeneous distribution of pathogens in foods, as well as of culture media and detection protocol, all affect test results, especially because some foodborne pathogens can cause disease when relatively few microorganisms are ingested.

Another confounding variable for applying the risk assessment approach is identification of the true occurrence of acute illnesses from foodborne sources, for the most serious also are the most likely to be detected. The cause of a foodborne illness is more likely to be identified correctly if the symptoms are distinctive, e.g., bloody diarrhea, rather than general, e.g., gastroenteritis (watery diarrhea, abdominal cramps, and vomiting) syndrome.

Chronic sequelae, or secondary, after-effect illnesses possibly of long duration, such as neurological, cardiac, or rheumatoid syndromes, can occur after foodborne infection (Archer, 1984, 1985; Mossel, 1988), and these are unlikely to be either identified or linked to a foodborne cause. Some individuals retain pathogens in their intestinal tract or in other organs and excrete them sporadically. The carrier state is important because infective microorganisms can be transmitted directly to individuals by the fecal-oral route or indirectly through food, by the carrier who unknowingly may be infected but not ill, and is shedding the organism. The great variability of human responses depends on many factors to be discussed in this document and on other factors yet unsuspected.

2 Disease Characterization: Hazard Identification

Microbial foodborne diseases are caused by pathogenic viruses, bacteria, fungi, parasites, marine phytoplankton, and cyanobacteria. Severity of these diseases range from infections without apparent manifestations, to mild illness, to severe illness, to death. Virulence of the pathogen dose and resistance/susceptibility of the host dictate the outcome. Foodborne diseases are classified as *infections* (organism invades and penetrates intestinal mucosa), *toxicoinfections* (organism produces toxin while in the intestinal tract), and *intoxications* (organism produces toxin in food that is ingested).

Introduction

Foodborne disease is defined as any illness resulting from ingestion of contaminated food. Such an illness can arise from a microbial or a parasitic invasive infection (typically referred to simply as *infection*), toxicoinfection, or intoxication (Figure 2.1). Infectious, toxicoinfectious, or toxin forming microorganisms causing disease are called *pathogens*. Foodborne infections result when pathogenic microorganisms in ingested food grow in, or colonize, the intestines, often invading the mucosa or other tissues and thereby causing *invasive infections*. Foodborne toxicoinfections result when a microorganism from ingested food grows in the intestinal tract and elaborates a toxin or toxins that damage the tissues or interfere with normal organ or tissue function. Foodborne microbial intoxications are caused by ingestion of food containing poisonous chemicals or specific enterotoxins or neurotoxins produced by microorganisms. Classes and characteristics of pathogenic microorganisms and each of these types of illness, with examples and consequences, will be described in this chapter. Table 2.1 details types and severities of illnesses caused by foodborne pathogens.

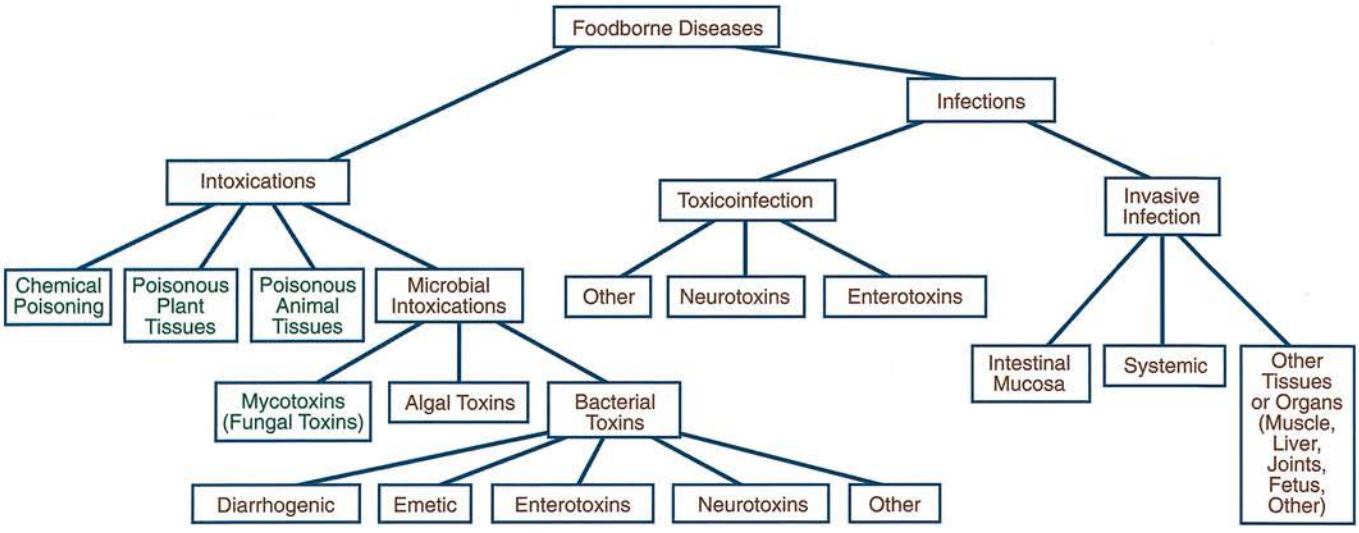

Figure 2.1. A classification of foodborne disease causes (adapted from Bryan, 1982). Diseases or toxins in red are addressed in this report.

Table 2.1. Characteristics of diseases caused by foodborne organisms and toxins. For some organisms, not all subspecies, types, strains, or serotypes are pathogenic or equally hazardous

Organism or toxin	Illness type [a]	Incubation period	Disease severity	Duration[b]	Sequelae[c]	Fatality: case rate[d] (%)	Toxic or infectious illness dose[e]	Other comments
Viruses								
Hepatitis A	F	1 to 7 weeks, usually 25 days	Moderate to severe	Weeks to months	?	0.3	Unknown[f]	Contaminated shellfish and prepared foods handled by infected workers.
Norwalk and Norwalk-like	F	1 to 2 days	Mild to moderate	1 to 2 days	—	0.0	Unknown[f]	Contaminated shellfish and prepared foods handled by infected workers.
Bacteria								
Aeromonas hydrophila	Unknown	—	Mild, self-limiting	Days to weeks	Yes	—	?	No confirmed foodborne cases; strong indirect evidence.[g]
Bacillus cereus Diarrheal:	T/F	8 to 16 h	Mild, self-limiting	1 day	—	0.0	10^5 to 10^{11} CFU (estimated from pop. detected in implicated foods assumes 100 g food consumed)	Emetic illness associated with cooked rice and pasta prepared in food service establishments. Emetic toxin heat resistent.
Emetic:	T	0.5 to 5 h						
Brucella abortus	F	—	Moderate to severe	Weeks	Yes	—	?	U.S. incidence declining. Usually foodborne in raw goat milk and cheese.
Campylobacter jejuni and *coli*	F	1 to 7 days	Mild to moderate	Days	2 to 10%	0.05	≥ 500 CFU	Associated with raw milk, poultry, beef, pork, shellfish.
Clostridium botulinum	T, T/F	12 to 36 h	Severe	Days to months	—	7.5	Up to about 10^9 LD_{50}/mg toxin in mice[h]	T/F for infants only. Most illness due to home-canned or fermented foods; occasionally mishandling in food service. Most due to vegetables (peppers, pimentos), meat, fish.
Clostridium perfringens	T/F	8 to 16 h	Mild, self-limiting	1 day	—	< 0.1	10^6 to 10^{10} CFU	Most outbreaks from meat and poultry products and beans; foods mishandled in food service establishments.

Table 2.1. (continued)

Organism or toxin	Illness type [a]	Incubation period	Disease severity	Duration[b]	Sequelae[c]	Fatality: case rate[d] (%)	Toxic or infectious illness dose[e]	Other comments
Coxiella burnetii	F	2 to 4 weeks	Mild to severe	Days to weeks	Yes	—	?	Raw milk; controlled by milk pasteurization
Escherichia coli O157:H7 (enterohemorrhagic)	T/F	3 to 7 days	Moderate to severe	Days to weeks	Yes	2.0	Estimated to be 10^1 to 10^3 CFU	Most outbreaks associated with insufficiently cooked ground beef in food service establishments and in nursing homes; also associated with raw milk.
E. coli (enteropathogenic)	(F?)	1 to 6 days	Mild to moderate	Days to weeks	?	≤ 0.1[i]	Estimated to be 10^6 to 10^{10} CFU for adults	Unlikely to be a significant cause of foodborne illness in the U.S., Canada, or W. Europe. Most cases in young children in tropical areas with poor hygienic standards.
E.coli (enteroinvasive)	F	1 to 3 days	Mild to moderate	Days to weeks	?	≤ 0.1[i]	10^8 CFU for adults with no underlying illness	Unlikely to be a significant cause of foodborne illness in the U.S. or Canada. Most cases in young children in tropical areas with poor hygienic standards.
E. coli (enterotoxigenic)	T/F	1 to 3 days	Mild to moderate	Days	?	≤ 0.1[i]	10^6 to 10^8 CFU for adults with no underlying illness	Most cases in tropical countries with poor hygenic standards. Cases in U S. are rare; most are associated with foreign travel. Most common cause of travelers' diarrhea. Highest incidence in children < 2 yrs in developing countries.
Listeria monocytogenes	F	4 days to several weeks	Mild to severe	Days to weeks	?	0 to 30[j]	?	Most severe form of illness occurs in the unborn, newborn, and immunocompromised. Pregnant women transmit to fetus.

Table 2.1. (continued)

Organism or toxin	Illness type [a]	Incubation period	Disease severity	Duration[b]	Sequelae[c]	Fatality: case rate[d] (%)	Toxic or infectious illness dose[e]	Other comments
Mycobacterium bovis, avium, and *tuberculosis*	F	4 to 6 weeks	Severe	Weeks to months	?	—	10^6 CFU for adults	Currently not foodborne in U.S.
Salmonella typhi and *paratyphi*	F	7 to 28 days	Severe	Weeks to months; possible relapses	Yes	6.0	$< 10^3$ to 10^9 CFU	Outbreaks frequently waterborne; contaminated shellfish or foods handled by carriers and not subsequently heated. Rare in U.S.
Salmonella serovars	F	6 to 48 h	Mild to severe	Days to weeks	2 to 3%	< 0.1	1 to about 10^9 CFU[k]	Commonly meat, poultry, milk, eggs, but numerous other foods involved (e.g., chocolate, peanuts, etc.).
Shigella spp.	F	1 to 7 days	Moderate to severe	Days to weeks	2 to 3%	0.1	10^1 to 10^6 CFU	Poor personal hygiene of infected food handlers responsible for most cases.
Staphylococcus aureus	T	2 to 7 h	Mild to severe (rarely)	Less than one day to several days	—	< 0.02	< 1 μg	High-protein foods; foods handled frequently during preparation (e.g., meat, salads); tolerates salty foods (e.g., ham). Enterotoxin heat resistant.
Streptococcus group A	F, T/F	1 to 2 days	Mild to moderate	Days to weeks	?	< 0.03	?	—
Vibrio cholerae (O1)	T/F	1 to 3 days	Mild (rarely) to severe	Days	—	< 1.0[l]	10^6 CFU	Outbreaks frequently associated with seafood. Many other foods involved. Rare in U.S.
V. cholerae (non-O1)	F, T/F	1 to 3 days	Mild to moderate	Days	—	< 1.0[l]	10^6 to 10^8 CFU	Outbreaks associated with seafood, mainly in shellfish in southern waters.
V. parahaemolyticus	F	1 to 3 days	Mild, self-limiting	Days	Yes	< 1.0[l]	10^5 to 10^7 CFU	Most cases associated with seafood (some cross-contamination).

Table 2.1. (continued)

Organism or toxin	Illness type [a]	Incubation period	Disease severity	Duration[b]	Sequelae[c]	Fatality: case rate[d] (%)	Toxic or infectious illness dose[e]	Other comments
V. vulnificus	F	Median 16 h	Severe	Days to weeks	—	0 to 60[l]	Estimate 1 CFU for persons with elevated serum iron concentration	All known cases associated with seafood, especially raw oysters. Most victims are male and have chronic liver or blood-related disorders.
Yersinia enterocolitica	F	1 to 3 days	Mild to moderate, self-limiting; chronic	Days to weeks	2 to 3%	0.03	?	Sometimes mimics appendicitis; linked to chronic reactive arthritis and Reiter's syndrome; associated with pork, milk, or milk products; carried by swine.
Parasitic protozoa								
Cryptosporidium parvum	F	1 to 2 weeks	Moderate to severe	4 days to 3 weeks	Yes	—	< 30 cysts	Water, marine fish. Possibly associated with raw milk and raw vegetables.
Entamoeba histolytica	F	2 to 4 weeks	Mild to severe	Weeks to months		—	5 cysts	Contaminated vegetables. Rare or nonexistent in U.S.
Giardia lamblia	F	5 to 25 days	Mild to moderate	Weeks to years	Yes	—	10 cysts	Rarely foodborne, primarily water-related cases. Salads and ice have been implicated.
Toxoplasma gondii	F	—	Mild to severe	—	?	—	1 cyst	Pork, insufficiently cooked hamburger.
Other parasites								
Anisakid nematodes	F	—	Mild to severe	—	?	—	1 larva	Marine fish.
Diphyllobothrium spp.	F	—	Mild to moderate	—	?	—	1 larva	Transmitted by freshwater fish, severe illness for highly immunocompromised individuals.
Taenia saginata and *T. solium*	F	—	Mild to severe	—	Yes	Significant for *T. solium* neurocysticercosis	1 cyst	Beef, pork.
Trichinella spiralis (nematode)	F	—	Moderate to severe	—	Yes	—	1 to 500 larvae	Primarily from undercooked pork, game meat, bear meat, walrus meat.

Table 2.1. (continued)

Organism or toxin	Illness type [a]	Incubation period	Disease severity	Duration[b]	Sequelae[c]	Fatality: case rate[d] (%)	Toxic or infectious illness dose[e]	Other comments
Toxins								
Paralytic shellfish poisons (PSP)	T	Minutes to 6 h	Mild to severe	Several days	—	1 to 4%	≥ 100 μg	Shellfish only from NE or NW coasts in U.S. and North America. Also in Central America and Asia.
Ciguatoxins	T	Minutes to 24 h	Mild to severe	Up to several months	—	May be as high as 13%	40–70 ng	Tropical fish only.
Diarrhetic shellfish poison	T	—	Mild	—	—	Low	≥ 32–77 μg[m]	Asia, Europe; two outbreaks on North American east coast.
Domoic acid	T	—	Moderate to severe	Hours to permanent	—	Unknown	≥ 60 mg[n]	Amnesic shellfish poisoning associated with mussels and clams.
Neurotoxic shellfish poison (brevetoxins)	T	—	—	Several days	—	Low	> 80 μg	Shellfish in southern states. May be associated with Red Tide (including prebloom).
Histamine, histaminelike (scombroid)	T	Minutes to 6 h	Mild to severe	≤ 1 day to 2 days	—	0.01%	≥ 50 mg histamine[o]	Mainly mackerel, tuna, mahi-mahi, blue fish.
Tetrodotoxin	T	Minutes to 3 h	Moderate to severe	Hours	—	May be as high as 50%	May be similar to levels for PSP	Puffer fish only, no recent cases in U.S.

[a]T = intoxication, F = infection, T/F = toxicoinfection.

[b]Excluding sequelae that may last 6 mo to 30 yr (Archer and Kvenberg, 1985).

[c]Sequelae only recently are being investigated for certain diseases. These include reactive arthritis, Reiters' syndrome, Guillain-Barrê-syndrome, ankylosing spondylitis, rheumatoid arthritis, septic arthritis, and cardiac manifestations (Archer and Kvenberg, 1985). A — in this column means sequelae are not thought to occur and/or there is no evidence or reason to believe that they do. A ? indicates occurrence of sequelae is unknown.

[d]From Todd, 1989b. Preliminary estimates of costs of foodborne disease in the United States. *J. Food Prot.* 52:595-601.

[e]For intoxications, toxic dose estimates are indicated. For infections and toxicoinfections, doses are those causing infection (often asymptomatic) or illness, probably the latter. See text for explanation. A ? indicates lack of available information or information so speculative as to permit little confidence. CFU = colony forming units.

[f]Hepatitis A and Norwalk virus are unable to be cultivated and counted; therefore the infectious dose is unknown.

[g]Kirov, 1993.

[h]LD_{50} = lethal dose for 50% of the population.

[i]≤ 0.1 is total fatality:case rate for all *E. coli* illnesses except *E. coli* O157:H7.

[j]For infants, fetuses, or adults with underlying illnesses or compromised immune systems. For healthy adults, fatality rate is nil.

[k]Low number related to ingestion of contaminated foods that are protective to the pathogen.

[l]There are about 50 known cases of *V. vulnificus* septicemia each year, of which about 30 die. These persons have predisposing factors to infections. There are probably many others with mild infections for which the mortality rate is likely to be low or nil. Thus, the upper limit is probably much higher than would be calculated if mild cases were considered.

[m]Todd et al., 1993.

[n]Todd, 1993.

[o]Todd and Holmes, 1993.

Sources: Archer and Young, 1988; Benenson, 1990; Bean et al., 1990a, 1990b; Doyle, 1989; *The Merck Manual*, 1992.

Classification of Pathogenic Microorganisms

Pathogens include, in increasing order of size, viruses, bacteria, protozoa, and other parasites. Almost all are microscopic as they occur in food although some parasites grow large enough in the body of the host, in this case the person eating the contaminated food, to be easily visible to the naked eye.

Viruses

Viruses are particles too small to be seen with a light microscope yet visible with an electron microscope. They are produced only within suitable living cells, that is, in a specific host species and in specific tissues within the body of the host. Viruses associated with foodborne diseases are known as *enteric* and are characterized by growth in the liver or intestinal cells and subsequent excretion in the feces. More than 100 types of enteric viruses exist although only a few have been proven to cause foodborne disease, e.g., hepatitis A and Norwalk-type viruses. Some enteric viruses migrate from the intestine to other organs, including the liver, the heart, or the brain, where these viruses may cause disease or death. Foodborne viral diseases differ in severity and only rarely cause death.

Because of the diversity of symptoms, the difficulty of detecting viruses in food, and for other reasons, documentation of viral foodborne diseases is scant. Food usually becomes contaminated by viruses when handled by an infected person or when coming in contact with sewage. Viral particles cannot reproduce outside the host cell but can survive in the environment. Host cells are induced by the virus to produce many progeny viral particles. If many host cells are recruited to produce viral particles and thereby are unable to carry out their normal functions or die, the host's body experiences disease; the more cells affected, the greater the severity.

Foodborne viruses cause only infections that are invasive in nature. They are unable to cause intoxications or toxicoinfections. Viruses increasingly are being recognized as significant causes of foodborne illness in the United States. A few outbreaks of hepatitis A transmitted through foods are recorded every year, and two outbreaks comprising a total of 5,000 cases made the Norwalk virus the leading cause of reported foodborne diseases in 1982. Other "Norwalk-like" viruses, much more rarely rotaviruses, and occasionally enteroviruses such as echovirus 4, are transmitted through foods in the United States. During the 5-year period 1983–1987, Norwalk virus ranked fifth, hepatitis A virus sixth, and other viruses tenth among identified causes of foodborne disease in the United States (see Table 5.1 in Chapter 5).

Bacteria

Bacteria are one-celled living microorganisms with a cell wall; their genetic material is not organized into a nucleus. Some bacteria contain an extra package of deoxyribonucleic acid (DNA) in a plasmid that is easily transmissible to other bacteria. Bacterial cells generally are either spherical or rod shaped and range from about 1 μm (one millionth of a meter) to 5 or 10 μm in length for the rods; thus, they can be seen with a conventional microscope. Numbers of bacterial cells increase when each cell divides into two "daughter" cells, which grow to full size and divide in two again. Thus, growth to large numbers can easily be achieved. Although bacteria can occur in great numbers in many foods, most bacteria usually are nonpathogenic. Bacteria and toxigenic fungi (the latter are addressed in a recent CAST report [1989]) are the only pathogenic microorganisms able to multiply in food.

Some pathogenic bacteria, including *Bacillus cereus*, *Clostridium botulinum*, and *C. perfringens*, form spores and thereby survive adverse environmental conditions. Sporeforming pathogens are significant because the spore form may occur in foods and it is resistant to many food preservation treatments designed to ensure food safety, e.g., boiling and selected sanitation treatments.

Pathogenic bacteria may cause foodborne infections, toxicoinfections, or intoxications. Infectious bacteria transmitted through foods in the United States include *Campylobacter jejuni*, enteroinvasive *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* serovars, *Shigella* spp., *Vibrio* spp., and *Yersinia enterocolitica*. *Salmonella* is the leading documented cause of foodborne infection in most developed countries, but *Vibrio parahaemolyticus* is the most significant foodborne disease agent in Japan. In the United States, other foodborne infectious bacteria are (1) rarely transmitted through foods; (2) formerly but no longer typically transmitted through foods; or (3) transmitted through foods only to persons whose resistance to infection is impaired greatly. For purposes of this report, infectious bacteria are invasive by definition. The number and severity of illnesses associated with various pathogenic bacteria are unknown.

The toxigenic bacteria most often documented as

transmitted by foods in the United States include *Bacillus cereus* (emetic type), *Clostridium botulinum*, and *Staphylococcus aureus*. These produce toxins in the food, and the organism itself is not subsequently required to cause illness.

The toxicoinfecting bacteria most often documented to cause foodborne diseases in the United States include *Bacillus cereus* (diarrheal type), *Clostridium perfringens*, enterohemorrhagic and enterotoxigenic *Escherichia coli*, and *Vibrio cholerae* (Popovic et al., 1993). The toxins produced in the gut by these bacteria have specific pathogenic mechanisms that require means of attachment and/or penetration of the intestinal epithelial cells and damage to specific cells.

Parasitic Protozoa

Parasitic protozoa are one-celled microorganisms without a rigid cell wall; their genetic material is contained in an organized nucleus. They are larger than bacteria, for their dimensions usually are greater than 10 μm. Their numbers also increase by twofold division, but only in hosts—not in foods. The form transmissible through food generally is called a *cyst* and is inert and resistant to the environment outside the host, similar to a bacterial spore but less resistent to heat. Once the cyst, by means of food, enters the body of a new host, it changes to an active feeding form (*trophozoite*) that can divide and multiply.

Protozoa associated with foods in the United States include *Entamoeba histolytica*, *Toxoplasma gondii* (Smith, 1993b), and *Giardia lamblia* (most often waterborne and rarely foodborne [Flanagan, 1992; Smith, 1993a]). *Cryptosporidium parvum* is an important cause of diarrhea on the west coast of Scotland and also a problem in immunocompromised people in the United States, e.g., acquired immune deficiency syndrome (AIDS) patients. Other protozoa occasionally are implicated as foodborne pathogens.

Other Parasites

Other parasites (as the term is used in this document) are multicelled animals living at the expense of larger host animals. In foods, parasites may occur in the form of eggs, larvae, or other immature forms. All eggs and some larval forms are microscopic. The nematode *Trichinella spiralis* is reported to cause a few cases of foodborne illness (trichinosis) in the United States each year. Trichinosis is the only reportable foodborne parasitic disease in this country. Formerly, this was an important pathogen associated with undercooked pork. Other nematodes of concern include the anisakids (especially *Anisakis simplex* and *Pseudoterranova decipiens*), which are associated with marine fish. Tapeworm species occurring in the United States, where reported cases are extremely rare, include the beef tapeworm (*Taenia saginata*), the pork tapeworm (*T. solium*), and the fish tapeworm (*Diphyllobothrium* spp.). Flukes (flatworms) transmitted through foods in other countries essentially do not occur in the United States. However, mild forms of all these parasitic diseases probably go unrecognized.

Foodborne Infections

A foodborne infection occurs when a microorganism in ingested food establishes itself in the human host's body and in most instances multiplies. All classes of foodborne pathogens (viruses, bacteria, parasitic protozoa, and other parasites) include infectious agents.

Viruses and the protozoon *Toxoplasma gondii* replicate exclusively within host cells; these are obligate intracellular parasites. Pathogenic bacteria that are not obligate intracellular parasites, e.g., *Salmonella* serovars and *Shigella* spp., invade intestinal cells and multiply. For example, *Shigella* spp. erode the intestinal lining, causing shigellosis, or "bacillary dysentery"; *Salmonella typhi* may enter the bloodstream and spread throughout the body, causing typhoid fever. Most serovars of *Salmonella*, however, penetrate the intestinal lining without progressing deeply into other tissues and seldom infect the bloodstream.

Parasites are invasive and can interfere with the function of many tissues and cause local discomfort. Adult tapeworms are noninvasive but adversely affect the host by competing for nutrients. For example, *Diphyllobothrium latum* has a special affinity for vitamin B_{12} and thus sometimes causes pernicious anemia in the host. *Giardia lamblia* trophozoites attach to the mucosa and evidently causes illness only if their numbers become so great that they obscure the absorptive surface and interfere with nutrient uptake.

Bacteria causing disease through infections often possess colonization or adherence factors allowing them to attach and to multiply in specific parts of the intestines despite peristaltic movement and the general flow of mucus and food suspension. When pathogenesis is based on colonization and subsequent toxin production, the illness is called a *toxicoinfection*. The toxicoinfective pathogens described next may be considered a noninvasive subset of the infective

pathogens.

Infections are a consequence of the growth of a microorganism in the human body. Thus, the time from ingestion until symptoms occur (*incubation period*), generally is rather long, compared with that for most foodborne intoxications. The incubation period depends on a variety of factors, which are discussed in Chapter 3, but usually is measured in days—unlike that of intoxications, which often are measured in hours. Fever, as a result of the host's response to invasion, often is associated with foodborne infections but rarely with foodborne intoxications.

Infected persons not only may experience illnesses themselves but may be sources of infection to others. In the period before illness, an infected person is a carrier and excretes the infective agent, e.g., hepatitis A virus (HAV) (Cliver, 1994a, 1994b; Riemann and Bryan, 1979). Certain microorganisms also can be excreted during the convalescent period (e.g., *Salmonella typhi*, other *Salmonella* serovars, and *Shigella* spp.), and chronic carrier states occur. Certain individuals never show signs of illness, but as healthy carriers can spread pathogens unknowingly to others. The carrier state usually ceases spontaneously after several weeks or a few months, but some individuals may become chronic carriers, i.e., for periods exceeding a year, for agents such as *Salmonella typhi*.

Chronic sequelae may be associated with infections from foodborne pathogens (Table 2.2). The incidence

Table 2.2. Certain foodborne infections and their complications (adapted from Mossel, 1988)

Bacterial and parasitic infection transmitted by foods	Complication/sequelae
Bacterial infections	
Aeromonas hydrophila enteritis[a]	Bronchopneumonia, cholecystitis
Brucellosis	Aortitis, epididymo-orchitis, meningitis, pericarditis, spondylitis
Campylobacteriosis	Arthritis, carditis, cholecystitis, colitis, endocarditis, erythema nodosum, Guillain-Barré syndrome, hemolytic-uremic syndrome, meningitis, pancreatitis, septicemia
Escherichia coli (EHEC-types) enteritis	Erythema nodosum, hemolytic uremic syndrome, seronegative arthropathy, thrombotic thrombocytopenic purpura
Q-fever	Endocarditis, granulomatous hepatitis
Salmonellosis	Aortitis, cholecystitis, colitis, endocarditis, epididymoorchitis, meningitis, myocarditis, osteomyelitis, pancreatitis, Reiter's disease, rheumatoid syndromes, septicemia, splenic abscesses, thyroiditis, septic arthritis (sickle-cell anemic persons)
Shigellosis	Erythema nodosum, hemolytic-uremic syndrome, peripheral neuropathy, pneumonia, Reiter's disease, septicemia, splenic abscesses, synovitis
Vibrio parahaemolyticus enteritis	Septicemia
Yersiniosis	Arthritis, cholangitis, erythema nodosum, liver and splenic abscesses, lymphadenitis, pneumonia, pyomyositis, Reiter's disease, septicemia, spondylitis, Still's disease
Parasitic infection	
Cryptosporidiosis[b]	Severe diarrhea, prolonged and sometimes fatal
Giardiasis[b]	Cholangitis, dystrophy, joint symptoms, lymphoidal hyperplasia
Taeniasis	Arthritis, cysticercosis (*T. solium*)
Toxoplasmosis	Encephalitis and other central nervous system diseases, pancarditis, polymyositis
Trichinosis	Cardiac dysfunction, neurologic sequelae

[a]Suspected to be foodborne or waterborne.
[b]Waterborne.

of sequelae after foodborne illness is unknown but probably is less than 5%. Types of sequelae include ankylosing spondylitis, cardiac manifestation, chronic incapacitating diarrhea, Guillain-Barré syndrome (GBS), reactive arthritis, Reiters' syndrome, rheumatoid arthritis, and septic arthritis (Archer and Kvenberg, 1985). Susceptibilities differ and may be linked to several host risk-factors.

Foodborne Toxicoinfections

Infective foodborne bacteria that are noninvasive and cause illness by producing toxins while growing in the human intestines are termed *toxicoinfective microorganisms*. *Vibrio cholerae*, the agent of cholera, is well-known to colonize the lumen of the intestine and to produce a toxin (choleragen) causing an outpouring of fluid from the exposed epithelial cells. Although the mucosa is not disrupted, death of the patient due to dehydration is possible. Other toxicoinfectious bacteria include *Bacillus cereus* (diarrheal type), *Clostridium perfringens*, *C. botulinum* (when infant botulism has occurred due to, for example, consumption of honey contaminated with *C. botulinum* spores), and enterohemorrhagic and enterotoxigenic *Escherichia coli* (Doyle, 1991a; Olsvik et al., 1991; Padhye and Doyle, 1992). Verocytotoxins (or *Shigella*-like toxins) produced by *E. coli* O157:H7 and other verotoxigenic *E. coli* adhere to receptors in the intestine, kidney, and central nervous system to prevent protein synthesis and cause cell death. The result is hemorrhagic colitis, hemolytic uremic syndrome, or thrombotic thrombocytopenic purpura, depending on the site of action. The onset times for toxicoinfections are frequently, but not necessarily, longer than those for intoxications but shorter than those for infections.

Foodborne Intoxications

Foodborne intoxication most often occurs when, during their growth, specific pathogenic bacteria release toxins into food that subsequently is consumed. Any indication that the food contains a toxin is rare by either appearance, odor, or taste (Sterksy et al., 1986).

The time it takes for symptoms to develop after consumption of foods containing microbial toxins often is useful initially in differentiating intoxications from infections. Generally, intoxications are manifested more rapidly after consumption of contaminated food than are infections because time for growth and invasion or elaboration of the toxin in vivo is not required. For example, in cases of *Staphylococcus aureus* intoxication, onset of symptoms usually requires from 1 to 6 hr. In cases of paralytic shellfish poisoning (PSP) (caused by eating shellfish containing a potent algal toxin), symptoms may be experienced within 15 minutes of ingestion. The precise times necessary for onset and the severity of intoxicating symptoms depend on many factors discussed in Chapter 3. Microbial toxins such as botulinum toxin and many of the marine algal toxins are some of the most potent known. For many, no antidotes exist.

Bacteria capable of causing foodborne intoxications include *Bacillus cereus* (emetic type), *Clostridium botulinum*, and *Staphylococcus aureus*. For a typical intoxication to occur, (1) the bacteria must be able to survive and to grow in the food and (2) they must be able to produce toxins in it. In some instances, toxigenic bacteria can contaminate foods without toxin production. Thus, the presence of the bacteria does not necessarily mean that the food is hazardous to consume. On the other hand, the microorganism may have grown in a food and produced the toxin, yet the microorganism no longer is recoverable from the food. Nonetheless, the toxin remains.

Ability to detect the toxin, therefore, is more important than ability to detect the viable cells. It generally has been more expensive and analytically more difficult to detect toxins than to recover and to identify the bacteria producing them. Fortunately, animal bioassays are being replaced by new biotechnologically derived methods. Bioassays initially using animals still are required for detection of any previously unidentified toxins.

In North America, several kinds of seafood toxins have caused disease associated with consumption of fish and shellfish (Baden et al., 1994; Juranovic, 1991) and their impact may be increasing (Anderson, 1994). Paralytic shellfish toxin (Levin, 1991), found mainly in western coastal waters and in the Gulf of St. Lawrence, Bay of Fundy, and Maine, is transmitted to humans through mussels, clams, and scallops that have ingested toxic dinoflagellates of the genus *Alexandrium*. Poisonings have been recorded from historical times (Todd, 1993b). Diarrhetic shellfish poisonings, from dinoflagellates of the genus *Dinophysis*, however, have been documented only since 1990 in two outbreaks from cultured mussels in eastern Canada. Many illnesses occur each year in Japan and western Europe. Certain strains of the diatom *Pseudonitzschia* produce domoic acid, responsible for over 100 cases and 3 deaths in eastern Canada in a 1987 outbreak, and also for closures on the western U.S. and Canadian coasts for razor clam and Dungeness crab fishing (Todd, 1993a). Ciguatera poisoning as a

result of ingestion of ciguatoxin and related toxins, occurs only in tropical fish. Therefore, most persons at risk are those eating fish in the Pacific and northern Caribbean. However, occasionally imported fish have caused outbreaks both in the United States and Canada. Scombroid poisoning, arising from bacterial spoilage of fish and production of histamine, is relatively frequent compared with other seafood toxin poisonings; tuna, mackerel, mahi-mahi, and marlin typically are implicated. Unfortunately, none of these toxins is destroyed by heat or cold storage, and control depends on the preprocessing stages.

Intoxications also may result from fungal toxins (*mycotoxins*) produced by molds in foods. Economic and health risks of mycotoxins were the subject of a 1989 CAST report (Council for Agricultural Science and Technology, 1989). This subject as well as diseases not of microbial origin have been omitted from the present report.

3 Dose Response Assessment

The digestive tract is the initial site of action by microbial foodborne disease agents, whether infective organisms or toxins. The body has defenses against these, but an overwhelming dose or a weakened host resistance leads to an infection or intoxication.

Certain populations, e.g., the immunocompromised, immunosuppressed, or already diseased, are at high risk for foodborne disease. Attempts are being made to predict the conditions and likelihood of infection through models extrapolated from known data. The minimum dose to cause illness is difficult to determine because of all the variables that must be considered: the agent, the host condition, and the concentration of the agent reaching the digestive tract. A successful infection or intoxication can result in mild to severe illness or even death.

Introduction

Ingested pathogens enter the body by way of the digestive tract, which therefore is a human being's main defense against such pathogens. An understanding of the digestive tract is necessary if one is to explain (1) how foodborne pathogens establish themselves and cause illness, (2) why illness may not always occur, (3) why individuals have different susceptibilities to pathogens, and (4) what the number of microorganisms (infectious dose) or the quantity of toxin (toxic dose) required to cause illness is.

Components of the Digestive Tract

Introduction

The gastrointestinal (GI) tract is under constant siege. Even if foods were sterile, many of their components are potentially toxic or allergenic. The normal flora both of foods and of the GI tract can, in immunocompromised persons, colonize or invade the body and cause disease. Therefore, a functional definition of *normal*, as applied to both the human host and the microflora, is that they are able to live in peace with each other most of the time. Microorganisms are recognized as pathogenic if they wage "war" with at least temporary success on individuals whose immune systems are not obviously impaired. This section will examine how the GI tract maintains or restores peace when assaulted by pathogens.

The GI tract serves as the first line of defense against the actions of potential foodborne pathogenic microorganisms. To cause illness, these microorganisms or their toxins first must be present in the food ingested by the host and second must be able to enter or to attack the body of the host by overcoming its defense mechanisms. Illness results when either the sheer number of microorganisms or the concentration of their toxins overwhelms the host's susceptibility threshold. This threshold may differ from person to person and may be affected by a number of factors described in detail later. For infective or toxicoinfective pathogens, the susceptibility threshold is termed the *infectious dose*; for toxins, the *toxic dose*. As the amount of toxin consumed exceeds this threshold, the severity of illness usually increases.

The Digestive Tract

To understand how the digestive tract can serve as a defense mechanism against the microbial world, one should recognize its components and essential functions. These are illustrated schematically in Figure 3.1. Humans need a digestive tract to obtain basic organic molecules and energy. The large molecules of proteins, fats, and carbohydrates contained in ingested food cannot be used as such and must be digested into smaller molecules by enzymes in the GI tract. These smaller molecules are transported or absorbed across the intestinal wall into the blood and the lymph. Hence, the molecules gain entry into the body and are used either directly for energy or indirectly for synthesis of proteins, lipids, carbohydrates,

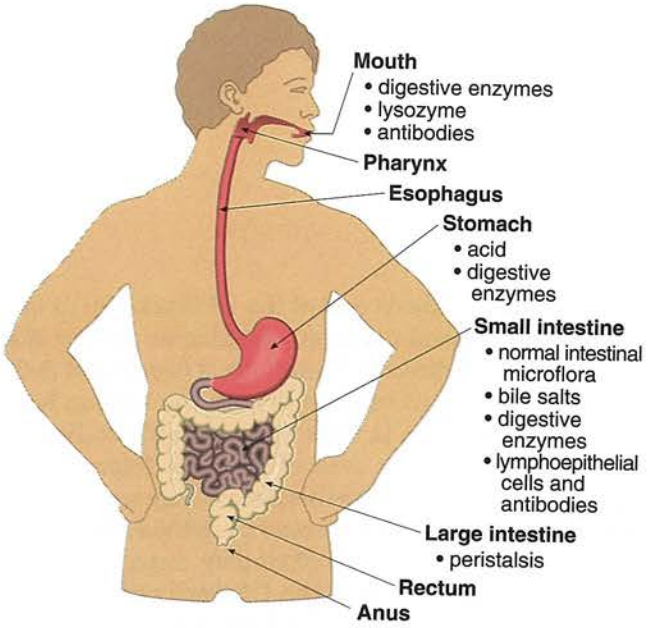

Figure 3.1. The organs and selected antimicrobial components or properties of the gastrointestinal tract (adapted from Taylor, 1990).

and other bodily components.

The GI tract is a tube with an epithelial lining and is open at both ends (mouth and anus) so that its contents actually are outside of the body. The open space at the center of the tube is called the *lumen*. The organs of the GI tract include oral cavity (mouth), pharynx, esophagus, stomach, small intestine, and large intestine. Accessory digestive organs include teeth, tongue, salivary glands, liver, and pancreas.

As food enters the digestive tract, it is chewed, mixed with saliva, and swallowed. Antimicrobial components of the saliva include lysozymes, other enzymes, and secretory antibodies. Once the food is swallowed, the mass, or *bolus*, is propelled through the rest of the digestive tract by *peristalsis* or the rhythmic contractions of muscles surrounding the tube. The swallowed bolus passes through the pharynx and the esophagus to the stomach, which stores the food as it is mixed with gastric secretions. Because hydrochloric acid (HCl) is present, the gastric juices of the healthy adult normally are quite acidic, with a pH of less than 2.

The acidity of the stomach facilitates digestion. The *pylorus*, or closure between the stomach and the intestine, retains materials in the stomach for exposure to HCl and to *pepsin*, a protein-digesting enzyme. From the stomach, the partly digested food, or *chyme*, as it now is called, passes into the small intestine, where most digestion and absorption occur.

The small intestine, approximately 20 feet (ft) (610 centimeters [cm]) long and 1 inch (in.) (2.5 cm) wide, comprises the duodenum, jejunum, and ileum and affords the majority of the surface at which the digestive tract interacts with the chyme. There is an epithelial lining only one-cell thick that faces the lumen of the intestine and mediates exchanges between the chyme and the deeper tissue layers containing blood and lymph vessels, glands, and nerves (Figures 3.2 and 3.3). Many enzymes in the small intestine digest (hydrolyze) carbohydrates, proteins, and other large molecules. Absorption of the small, digested molecules occurs primarily in the jejunum and is quite rapid because of the extensive surface area afforded by the folds (*plicae*) and projections (*villi*) in the lining. This surface is further augmented by microscopic projections (*microvilli*) on the epithelial cells; because of their microscopic appearance, the coat of microvilli is known as the *brush border*.

The last major organ entered by the chyme is the *large intestine,* comprising the colon and rectum. It is about 5 ft (150 cm) long by 2.5 in. (6.5 cm) in diameter, and has little digestive function. The large intestine absorbs water and electrolytes (e.g., sodium and potassium) from the chyme, forming, storing, and expelling from the body indigestible waste products as feces. The chyme is propelled through the GI tract by peristalsis.

Defense Mechanisms

The components of the defense mechanism of the host GI system include (1) an acidic stomach; (2) an active intestinal immune system; (3) a resident or indigenous intestinal bacterial flora, which may exclude pathogens; (4) highly concentrated bile salts

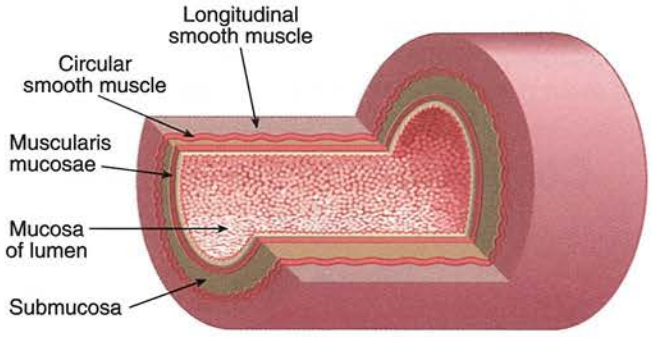

Figure 3.2. Diagram of the layers of the small intestine (adapted from Taylor, 1990).

and digestive enzymes able to kill certain microorganisms; (5) mucus; and (6) peristaltic action, which is able to reduce the ability of certain pathogens to colonize. The relative impermeability of the healthy GI mucosa to intact particles such as whole bacteria or to large molecules such as toxins also is a part of the GI defense mechanism although recent evidence indicates that the healthy GI tract is not as impenetrable to large protein molecules as once believed. Small quantities of immunologically important intact proteins and large peptides can be absorbed and can enter the circulation under normal circumstances. Such absorption may be important to immune function for production of antibodies to foreign proteins and may be involved in development of food allergies and other diseases.

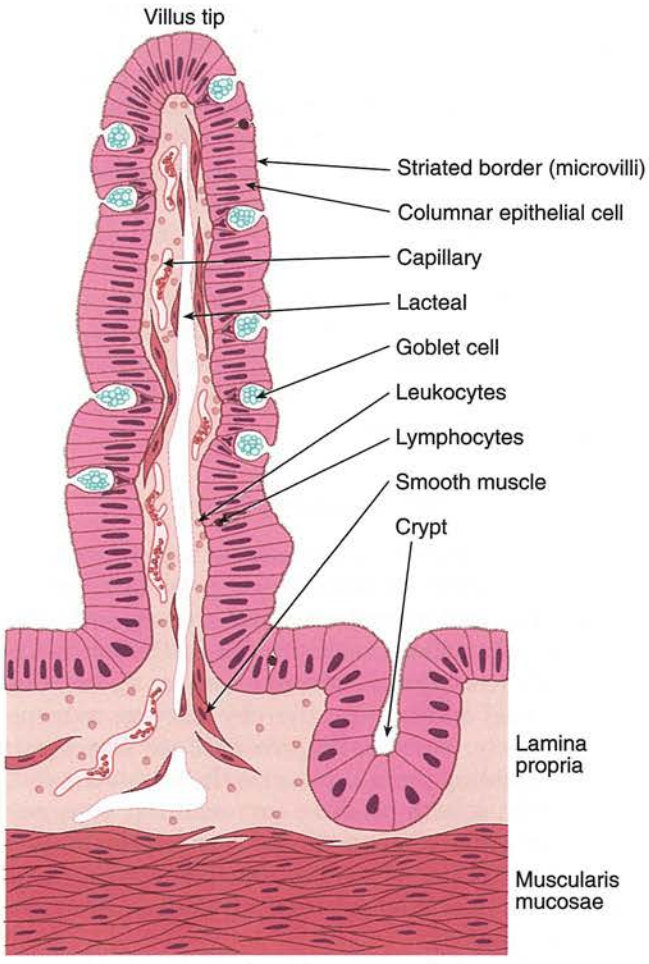

Figure 3.3. A villus from the small intestine with adjacent crypt showing cellular diversity and perfusion (adapted from Taylor, 1990).

When Defenses Fail

A foodborne infectious agent rarely affects all those eating a contaminated food. Any drug, food, or disease state able to alter or to affect the GI defense system adversely can render the host relatively susceptible when challenged by foodborne pathogenic microorganisms or by microbial toxins. Similarly, anything allowing the pathogen to bypass or to "fool" the defense system will increase the probability of illness. In either instance, fewer molecules of toxins or smaller numbers of pathogens are required to cause illness in a person at high risk than in one not, and the toxic or infectious dose is smaller in the former. Genetic factors as well as gender may play a role in determining susceptibility to foodborne illness.

Components of the Defense System and Attributes of Pathogens to Avoid Host Defenses

Stomach pH

Whether the person is healthy, immunocompromised, or ill, *stomach acidity*, or low pH, has a critical function for both digestion of food and protection from disease. The gastric pH control system is complex in that it is directed by hormonal, neural, chemical, and mechanical factors. For illness to occur, a sufficient number or amount of most foodborne pathogens or microbial toxins must reach the small intestine. Low stomach pH, for example, can reduce numbers of or eliminate pathogenic microorganisms or toxic molecules before they reach the small intestine, where most absorption occurs.

Anything decreasing acidity, i.e., increasing pH, can protect acid-labile pathogens and toxins in ingested food and increase the chance of these agents reaching the small intestine in their active form. For example, such factors as buffering capacity of the food, i.e., the ability of ingested food components to increase stomach pH, excessive consumption of antacids (these also are buffering agents), or use of drugs (such as cimetidine and ranitidine for treatment of duodenal ulcers) inhibiting gastrin stimulated stomach-acid secretions can increase stomach pH. Partial and total gastrectomies also are associated with increased risk as a result of decreased acidity.

Reduced gastric acid secretion or gastritis (stomach inflammation) can occur with age and in certain

disease states. As a result, the pH of the proximal small intestine is increased (becomes more alkaline) and bacterial overgrowth with subsequent malabsorption of certain nutrients occurs.

The toxigenic bacterium *Clostridium botulinum* has an effective way of utilizing GI enzymes to cause illness while being protected against the acidity of the stomach. When it is growing in contaminated foods, it makes a protein toxin consisting of two or more subunits, only one of which is highly toxic to humans and labile to stomach acidity. The other nontoxic subunit or subunits serves to protect the acid-labile subunit during passage through the stomach. The toxin when present in the complex is less neurotoxic in the host but is released from the complex by the intestinal proteolytic enzymes after passage through the stomach to the small intestine.

A person whose stomach acidity is reduced for any reason is exceptionally susceptible to illness after ingesting small numbers of infectious microorganisms or toxin molecules. Other factors such as quantity and composition of foods ingested (foods high in fat, for example, can protect pathogens), degree of mixing of the food bolus with saliva by chewing (which exposes foodborne pathogens and toxins to gastric acid), or damage to the gastric mucosa by such agents as aspirin may play a role in increasing the risk of foodborne illness. A sufficient number of foodborne microbial toxins or pathogens must reach the small intestine for illness to occur. For *Salmonella,* this number is known to be as few as one or two cells. Those managing to reach the small intestine then have to contend with its defense mechanisms.

The Intestinal Immune System

Components of the immune system of the healthy intestine can reduce absorption of some large molecules or reduce colonization or invasion of the epithelium by pathogens without affecting resident bacterial flora. Secretory antibodies present in the saliva also are protective.

The immune system of the GI tract is related to but distinct from that of the systemic immune system. The former protects the host from antigens that have crossed the epithelium and inhibits antigen uptake by promotion of brush border surface digestion. In the small intestine, lymphoid tissues (*Peyer's patches*) are covered by lymphoepithelial cells (*M cells*). A number of proteins, viruses, and inert particles can be transported by endocytosis into and across an M cell, in which they are exposed to subepithelial lymphocytes and an immune response is elicited. Thus, prior oral exposure to a protein antigen reduces the likelihood of absorption of that antigen intact. Reduction is accomplished by the immune system's working with the brush border intestinal enzymes.

In an immunized host, large molecules or particles such as toxins are immobilized in immune complexes in the mucosal epithelium. The immobilized form subsequently can be attacked gradually by protein-digesting enzymes. Another way in which the intestines minimize entry of large intact molecules or particles into the circulatory system is by binding them to receptors on the surface of the brush border membrane. The membrane invaginates to encapsulate the bound molecule or particle, which is broken down into smaller fragments. The GI immune system also can trigger production of intestinal mucus, which may protect additionally, especially against parasitic infection.

Some microorganisms can change their outside surfaces by altering their antigenic profile, so that they are not recognized and therefore not eliminated by the immune system of the host. Many microorganisms can make antigens resembling or mimicking those of the host and thus are recognized by the host as "self," considered harmless, and consequently not attacked by the host immune system. This strategy of molecular mimicry by some foodborne pathogens also seems to play a role in autoimmune reactions resulting in chronic diseases such as reactive arthritis in genetically susceptible humans. Microorganisms implicated as triggering reactive arthritis include serovars of *Salmonella* and species of *Shigella* and *Yersinia.*

The Intestinal Flora

To cause illness, infectious or toxicoinfectious pathogens must be able to compete successfully against resident microflora. Furthermore, pathogens must be able either to colonize the epithelial surface or to hide from the GI immune system by invading the mucosal epithelium, thereby gaining entrance into the body. Some pathogens produce attachment factors enabling them to colonize the intestinal walls effectively; others produce extracellular enzymes, toxins, or other compounds altering permeability or damaging epithelial cells so that pathogens can invade. Such microbial products or abilities are called *virulence factors.*

More than 400 species of bacteria live in the adult human GI tract. The bacterial population of the tract is so large that it exceeds the number of human cells in the body; in fact, bacteria are estimated to consti-

tute at least one-half of total fecal mass. The GI tract of the newborn is sterile at birth and becomes colonized by bacteria within a few days. Everyone older than one year has in the GI tract populations of indigenous bacteria numbering approximately 10^{14} (100,000,000,000,000) cells.

Each part of the GI tract has its own microbial flora uniquely adapted to the prevailing microenvironment of pH, oxygen tension, and nutrient composition and availability. Although the large intestine has a stable flora, the flora in the small intestine is unstable for some individuals. Whether the presence of a stable microflora in the small intestine affects susceptibility to foodborne toxins or pathogens is unknown.

Indigenous flora can provide resistance of the GI tract to colonization by pathogenic microorganisms. Animal studies indicate that colonization resistance exerted by the GI flora increases with age. Colonization resistance after weaning and throughout adulthood can be at least fivefold greater than that of the infant intestine. Although the stomach in healthy humans generally is free of stable microbial populations, lactic acid bacteria and some yeasts may be isolated from gastric contents.

Most foodborne pathogens are not normal inhabitants of the intestine of people of developed countries and in the healthy GI tract have difficulty competing with indigenous microflora. Notable exceptions are *Clostridium perfringens* and *Escherichia coli*, which usually are present in the large intestine.

The direct beneficial effect of the resident microorganisms is competition with the pathogenic, invading microorganisms. Additionally, the resident intestinal microflora indirectly may fortify the overall health and immunity of the host. Normal intestinal microflora may enhance development of immune response, produce vitamins necessary to overall health, and assist in digestion, thereby enhancing nutrient and energy availability of ingested food. In the healthy individual, host tissues and GI microflora operate in harmony. If this relation becomes unbalanced by disease or drugs, the nutritional status and the general health of the host can be affected adversely.

The resident intestinal microflora may have undesirable effects, including those of competing with the host for nutrients and possibly of producing carcinogens from food components. But given the documented benefits of normal resident intestinal microorganisms, antibiotic therapy for treatment of foodborne illness may be ineffective or actually may exacerbate the condition. Thus, such therapy, if thought necessary, should be used with care, especially if the pathogen is resistant and the resident microflora sensitive to the antibiotic. Oral doses of antibiotics decrease colonization resistance and can facilitate intestinal colonization by such pathogens as *Salmonella typhimurium* and *Vibrio cholerae*.

Bile Acids

Bile acids are synthesized in the liver from cholesterol and assist in digestion and absorption of fat. They greatly inhibit the growth of many microorganisms, including many pathogens. For example, bile acids are thought partly responsible for preventing *Clostridium botulinum* from living and producing botulinum toxin in the healthy intestinal tract. But enteric microorganisms such as *Escherichia*, *Salmonella*, and *Shigella* are resistant to bile acids.

Enzymes

Digestive enzymes are present and active throughout the GI tract. Many may inhibit or inactivate a variety of microorganisms. Notable is the presence in saliva of lysozyme, which hydrolyzes many bacterial cells causing death of the microorganism.

High-Risk Populations

In the United States today, an increasing percentage of the population is becoming especially susceptible to a great variety of pathogens (Table 3.1). The source of these includes, but is not limited to, food. Evidently, elderly individuals undergo a decrease in immune function and are more susceptible to microbial infections than are other healthy adults. This may occur as early as 50 to 60 years of age. The population older than 65 in 1989 accounted for 29 million, or approximately 10%, of the U.S. population, and the number is growing by about 1 million per

Table 3.1. Populations sensitive to foodborne disease in the United States (U.S. Department of Commerce, 1991; U.S. Department of Health and Human Services, 1993)

Population category	Individuals	Year
Pregnant women	5,657,900	1989
Neonates	4,002,000	1989
Elderly (over 65)	29,400,000	1989
Residents in nursing home or related care facilities	1,553,000	1986
Cancer patients (nonhospitalized)	2,411,000	1986
Organ transplant patients	110,270	1981–1989
AIDS patients	135,000	1993

year.

The immune system is affected adversely by a number of factors influencing individual susceptibilities to foodborne toxins and pathogens. External pressures on the host such as malnutrition, mental stress, and poor health all can reduce immune function. During infancy and old age, the immune system is less effective. The impaired nutritional status due to diarrhea, which often occurs in cases of foodborne illness, can affect the immune system adversely. Therefore, the severity and duration of the diarrheal phase of foodborne illness can affect the defense ability of the host.

Individuals immunocompromised as a result of transplant operations, chemotherapy, or AIDS also are susceptible to pathogens, including those that are foodborne. These individuals also may be infected by opportunistic pathogens commonly found in most foods, which pose little or no risk to the healthy. In some instances, immunocompromised individuals can be attacked by species of their own resident intestinal flora. The number of U.S. transplant patients requiring continued immunosuppressive therapy is increasing each year; numbers of heart, kidney, liver, and pancreas transplants have increased as much as 50% annually. These numbers undoubtedly will grow considerably in the next decade.

Currently, there are approximately 135,000 cases of AIDS in the United States, but 1 in 250 individuals in the United States has tested positive for the antibody to the AIDS-causing virus (human immunodeficiency virus [HIV]) and may develop clinical AIDS (Centers for Disease Control and Prevention, 1993a). There have been 201,775 adult and 2,615 child deaths from AIDS in this country. The total population of AIDS patients is at increased risk of a variety of microbial diseases, including those that are foodborne.

Thus, in total, more than 30 million individuals (Table 3.1) in the United States are likely to be at especially high risk for many of the microbial agents in food. Additionally, infants, hospitalized persons, individuals receiving immunosuppressive treatment, and chronically ill persons with disease such as cirrhosis are at increased risk of microbial infection. Persons on antimicrobial treatment, whether current or recently completed, add to these high-risk populations. Nearly one-third of all hospitalized patients are treated with antibiotics, and this probably is one of the important factors responsible for the recognized increased risk of microbial infection in hospitalized persons.

Other factors increase the susceptibility of an individual to foodborne illness. Poor personal hygiene will increase the likelihood of the individual ingesting pathogens and will affect others if the individual is a food handler or preparer. Pregnancy, for example, puts a woman, and her fetus, at special risk from infections with *Listeria monocytogenes* or *Toxoplasma gondii*. Each of these agents may cause abortion, stillbirth, or fetal abnormality. Infants and many children younger than 5 are especially susceptible because their immune systems are developed incompletely. These and other factors increasing the risk of foodborne illness are presented in Table 3.2.

Doses Causing Infection and Illness

Clearly, the probability of infection (i.e., establishment or colonization of pathogens in a human host, but signs of illness not necessarily present) or illness is a function of (1) the number of units of the infectious agent (viral particles; bacterial cells; protozoan cysts; or parasitic cysts, worms, or eggs) ingested with food; (2) the infectivity and pathogenicity of the agent; and (3) the vulnerability of the host. Microorganisms sharing the same genus and species name, e.g., *Escherichia* is the genus and *coli* the specific epithet, are not all identical and may differ greatly in their pathogenicity. In fact, some may not be capable of causing human illness while others are quite hazardous. This variability causes confusion in the assurance and regulation of food safety. For toxins, the likelihood and the severity of illness generally increase with the dose consumed. Certain foods may be especially efficient vehicles for transmission of infectious or toxic agents in that they enhance the probability of infection or illness from a small ingested dose. Foods with good buffering capacity, e.g., milk and hamburger, can protect pathogens from intestinal acidity.

Predictions of Infection Based Upon Probability Models

Probability models are beginning to be used to estimate the risk of infection after varied exposures to pathogens. These models are defined by a specific dose-response curve for each pathogen although it is recognized that risk depends on the number of microorganisms ingested (see Figure 3.4 for example). Similar models predict risk from chemicals and safety of drinking water. These predictive models will be increasingly effective as tools to estimate the impact

Table 3.2. Factors increasing the risk of foodborne infection or the severity of illness

Factors	Reasons
Microbial factors	
Type and strain of pathogen ingested	Some pathogens and strains more virulent than others
Quantity of pathogens ingested	Higher numbers ingested may increase severity of illness and/or shorten onset time
Host factors	
Age less than 5 years	Lack of developed immune systems, smaller infective dose-by-weight required
Age greater than 50 or 60 years (depending on pathogen)	Immune systems failing, weakened by chronic ailments, occuring as early as 50 to 60 years of age
Pregnancy	Altered immunity during pregnancy
Hospitalized persons	Immune systems weakened by other diseases or injuries, or at risk of exposure to antibiotic-resistant strains
Concomitant infections	Overloaded or damaged immune systems
Consumption of antibiotics	Alteration of normal intestinal microflora
Excessive iron in blood	Iron in blood serving as nutrient for certain organisms
Reduced liver/kidney function (alcoholism)	Reduced digestion capabilities, altered blood-iron concentrations
Possession of certain human antigenic determinants duplicated or easily mimicked by microorganisms	Predisposition to chronic illnesses (sequelae)
Surgical removal of portions of stomach or intestines	Reduction in normal defensive systems against infection
Immunocompromised individuals including those on chemotherapy or radiation therapy; recipients of organ transplants taking immunocompromising drugs; persons with leukemia, AIDS, or other illnesses	Immune system inadequate to prevent infection
Stress	Body metabolism changes allowing easier establishment of pathogens, or lower dose of toxin required for illness
Poor hygiene	Increased likelihood of ingestion of pathogens
Diet related factors	
Nutritional deficiencies either through poor absorption of food (mostly ill or elderly persons) or unavailability of adequate food supply (starving persons)	Inadequate strength to build up resistance and/or consumption of poor-quality food ingredients, which may contain pathogens
Consumption of antacids	Increased pH of stomach
Consumption of large volume of liquids including water	Dilution of acids in the stomach and rapid transit through the stomach
Ingestion of fatty foods (such as chocolate, cheese, hamburger) containing pathogens	Protection of pathogens by the fat against stomach acids
Other factors	
Geographic location	Likelihood of exposure to endemic virulent strains, limited food and water supply, varied distribution of organisms in water and soil

of food contamination as well as the costs and benefits of implementing control measures in food processing and handling. Appropriate application of predictive models relies on accurate methods for quantitation of pathogens and on knowledge of infectivity and illness rates for various human populations with various pathogens.

Two probability models have been used to estimate potential infections at various doses for *Shigella dysenteriae*, *S. flexneri*, poliovirus, echovirus, rotavirus, *Entamoeba coli*, and *Giardia lamblia* (Haas, 1983). Although these models do not address the common foodborne pathogens in the United States (Tables 2.1 and 5.1, see Chapter 5), predictions from the models are useful. These models suggest that one person in 1,000 to 10,000 could become infected if each ingest-

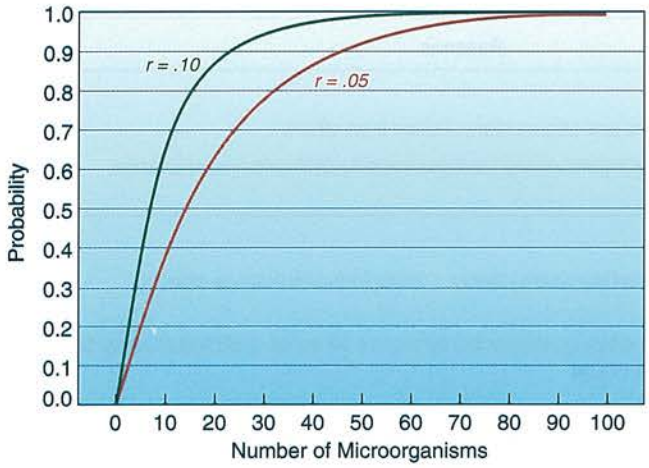

Figure 3.4. The probability of developing infection based on exposure and infectivity of the pathogen ingested. This model was selected as an example and is based on number of *Giardia* cysts (Rose et al., 1991). Other models are more appropriate for other types of infective pathogens.

Model: $P_i = 1 - \exp(-rN)$.
Where: P_i = probability of infection,
N = exposure, and
r = the parameter that defines the infectivity curve of the individual organism.

The probability times 100 is the chance of infection. A probability of 1 means infection is certain, a probability of 0.5 means there is a 50% chance of infection, a probability of 0 means infection will not occur, and so forth.

ed one bacterium whereas 2 to 30 people in 100 could become infected if each ingested one protozoan cyst or virus; thus, number of bacteria required for infection is predicted to be greater than that of viral particles or protozoan cysts.

Risk assessment models have been developed to evaluate the potential health effects of contaminated shellfish consumption. Rose and Sobsey (1993) used dose-response models developed from human feeding studies to estimate the risk of infection from contaminated shellfish. Of 58 pooled samples, 19% were positive for viruses. An echovirus-12 probability model was used to determine the individual risk from consumption of 60 grams of raw shellfish. Individual risks ranged from 0.00022 to 0.035 (numbers indicate the fraction of exposed individuals likely to become infected or 22 per 100,000 and 35 per 1,000, respectively). Individuals consuming raw shellfish from approved waters in the United States may have on average a 1 in 100 chance of becoming infected with an enteric virus. When the rotavirus model, which represents a more infectious virus, is used, the risk increases to 5 in 10. These predictions explain why outbreaks continue to occur. At large banquets, for example, hundreds of people can become infected if contaminated raw or lightly cooked shellfish is served.

Morbidity and mortality risks can be estimated from probabilities of infection depending on the virus. Table 3.3 compares risks of infection, illness (60 and 75%, respectively), and death (0.01 and 0.6%, respectively) for rotavirus and HAV. Exposure is set for a small serving of shellfish, with contamination ranging from 0.1 to 100 viruses per serving. The risk of infection is more than 10 times greater for rotavirus than for HAV; mortality, however, is much more significant for HAV. These models predict that for even a single serving of raw shellfish (or that cooked less than 1 minute) greatly contaminated with the

Table 3.3. Risks of infection, morbidity, and mortality for consumption of viral-contaminated raw shellfish for a single exposure (adapted from Rose and Sobsey, 1993)[a]

	Risk of infection		Risk of illness		Risk of death	
Virus levels/60 g[b]	Rotavirus	HAV[c]	Rotavirus	HAV	Rotavirus	HAV
000.1	0.054	0.0002	0.032	0.00015	0.0000032	0.0000009
1.0	0.27	0.002	0.16	0.0015	0.000016	0.000009
10.0	0.57	0.02	0.34	0.015	0.000034	0.00009
100.0	0.76	0.15	0.46	0.11	0.000046	0.00066

[a]The risk is the fraction of the population exposed who are likely to experience the consequence (infection, illness, or death).
[b]Single serving of 6 small shellfish.
[c]Assuming infectivity for HAV is equal to the echovirus–12 model, which is more moderate than the rotavirus. The mortality for HAV (0.6%), however, is much more significant than for rotavirus (0.01%).

viruses, risk of illness may be as great as 46 out of 100 individuals exposed and that of death may be as great as 7 out of every 10,000.

Not everyone exposed to enteric pathogens (bacteria, viruses, or protozoa or other parasites) will become clinically ill. Certain enteroviruses are known to cause asymptomatic infections. The development of clinical illness depends on the numerous factors detailed in the section "High-Risk Populations" and in Table 3.2. For HAV, the percentage of infected individuals with clinically observed illness is small for children (usually lower than 5) but increases greatly with age (Evans, 1982). In contrast, the frequency of clinical symptoms of rotavirus among infected persons is greatest in childhood (Gerba et al., 1985) and least in adulthood. The observed frequencies of symptomatic infections for various enteroviruses may range from 1% for poliovirus to higher than 75% for some of the coxsackie B viruses (Cherry, 1981). The frequency of clinical hepatitis A among infected adults is estimated at 75%; during waterborne outbreaks, however, it has been as high as 97% (Lednar et al., 1985).

Estimates of Doses Needed to Cause Illness

Experimental feeding trials often are used to establish the infective dose, yet they differ from an outbreak in that they usually are done with healthy young men, whereas an outbreak affects whoever is unfortunate enough to have eaten a contaminated food and most certainly includes highly susceptible members of the population. Thus, volunteer feeding studies may report mild or no illnesses for a given number of infectious agents consumed whereas, in actual outbreaks, lower levels of microorganisms may cause illness. As previously noted, the food vehicle may have a significant effect on pathogenic infectivity.

Data from foodborne illness outbreaks and human feeding studies indicate that the doses of infectious agents required to cause illness differ greatly among types, genera, species, and strains of infective microorganisms (Table 2.1). Depending on microorganism, person, and situation, doses range from one microorganism to hundreds of millions. Indeed, often the range provided for any given microorganism is quite broad.

There are many obstacles to accurately interpreting data from outbreaks and feeding trials. Often, reports do not make a clear distinction between asymptomatic infection and illness as an endpoint, a difference having a major impact on the estimated infective dose. The infective doses obtained from the literature and reflecting author opinion (Table 2.1) probably are actually a mixture of doses causing infection and illness; most likely, they reflect the latter more than they do the former. This discrepancy often may be responsible for the broad range of infective doses tabulated. Individuals vary greatly in susceptibility.

Limitations of sampling and laboratory methodology hinder interpretation of feeding trial or outbreak data. Additionally, one species of bacteria in foods may grow while others die. If temperature abuse of the food occurs, for example, numbers of pathogens determined at any given time will not necessarily reflect numbers of pathogens actually consumed. Hot holding of foods may cause death of and freezing may result in substantial declines in bacterial populations. Competition from spoilage microorganisms that are present may alter the number of pathogens in the food. The spoilage microorganisms also may interfere in laboratory assays to determine, qualitatively or quantitatively, the occurrence of the pathogen in a suspect food. Thus, all after-the-fact estimates of how many bacteria an affected person has ingested are speculative.

Doses of protozoa administered in feeding trials can be determined by the direct counting of cysts. Bacterial numbers in feeding trials or outbreaks are estimated indirectly by means of colony counts or are statistically based, most-probable-number determinations. Doses of viral particles usually are measured indirectly by determination of plaque-forming units or may be estimated from electron microscopic observations. Actual number of bacterial cells or viral particles often exceeds that of the colony- or plaque-forming units by a substantial factor, which seldom is known. Viral doses are especially difficult to estimate accurately because of methodological limitations.

Because of both human variability in response to the toxin and methodological difficulties in extracting it from food and in determining the amount of it present, estimates of toxic doses are of limited usefulness (Table 2.1) and cumbersome in the characterization of risk. These problems are compounded by variability in the amounts of toxin produced by different microorganisms of the same species in different environments.

Severity of Illness

Incubation periods for foodborne illnesses range from less than one hour to several weeks, and the duration of symptoms can range from a few hours to

several months (Table 2.1). Although acute effects are the only ones traditionally documented for foodborne diseases, some chronic consequences of infection have been observed. These sequelae may last a few weeks or months, or longer, and may include conditions not attributed commonly to enteric infections such as campylobacteriosis, salmonellosis, or yersiniosis.

Some chronic sequelae, e.g., hemolytic uremic syndrome, are more serious than the original gastroenteritis and in fact may occur in the absence of a frank, acute illness. The severity of illness (Table 2.1) depends on several factors, including agent type, amount consumed, individual health, individual susceptibility (Table 3.1), and agent protection by food during passage through the stomach. The more severe an illness, the more likely it is to be recognized and reported to health authorities. The cause of sequelae, however, may not be linked to a foodborne source.

A multitude of host factors contributes to determination of foodborne disease severity (Mims, 1987). The genetic constitution, as expressed by the immune response of a host, often contributes to individual susceptibility to infection (Finlay and Falkow, 1989). Because the immune system is a major line of defense against infection, immunosuppressed and immunocompromised individuals, infants, and the aged are more susceptible to infection by virulent and opportunistic pathogens and often have a more severe form of the disease. External host stresses such as malnutrition, mental stress, hospitalization, organ transplant surgery, and chemotherapy also contribute to the outcome of an infection. Research suggests that *Salmonella* resistant to antimicrobial agents are more dependent on host characteristics to cause disease than are *Salmonella* sensitive to antimicrobial agents (Riley et al., 1984).

Pathogenic microorganisms represent the result of dynamic evolutionary adaptation of survival strategies. The ability to evade partly or totally one or more of the normal defenses of the host is important (Gotschlich, 1983). Mechanisms used by pathogenic microorganisms to overcome host protective barriers include those related to adherence for entry into the host, intracellular localization for dissemination, secretion of toxins, and avoidance of host immune systems.

Concurrent Infections and Immunity

Concurrent infections with more than one agent (not all of which necessarily are foodborne) are likely to occur in developing countries but are less likely where foodborne infections are less common (e.g., the United States). Concurrent infections can greatly enhance the severity of illness caused by pathogens of low virulence and are quite likely to be misdiagnosed, i.e., only one of the infecting agents will be detected and identified as the causative agent.

Persons who have been exposed to a pathogen or to a toxin may have partial or total immunity when exposed later. The immunity results from a specific immune reaction and greatly increases the infective or toxic dose required to cause subsequent illness.

Vaccination may be used for a few pathogens to induce immunity in people before they ingest contaminated food. This protective strategy may be used before traveling abroad to areas with common incidence of pathogens in food or water. Unfortunately, vaccines are available against only a very few of the foodborne infectious agents. Highly effective (and expensive) vaccines against HAV now are becoming available.

Estimates of Death Rates

Foodborne pathogens may cause very mild to quite severe illnesses and may result in death. Accuracy of mortality rate determinations (Table 2.1) is affected by many of the same factors dictating the likelihood of clinical illness. Therefore, both morbidity and mortality rates must be considered in risk estimates. According to estimates of the World Health Organization, diarrheal disease, much of it foodborne, is the second leading cause of death worldwide; 5 million children per year die from diarrheal disease (ASM News, 1990). In the United States, death and serious sequelae from foodborne illnesses are less common. Death, when it occurs, is primarily in those who are highly susceptible.

4 Exposure Assessment

Most varieties of food contain some level of foodborne pathogens. The pathogens may increase in number, may produce toxins under favorable growth conditions, or may be destroyed by food preservation processes. Some bacteria, parasites, or viruses can survive adverse conditions, and bacterial spores are resistant to cooking and pasteurization. Freezing preserves the agents, which subsequently can grow and multiply under stable conditions. Some pathogens can grow during long-term refrigeration.

Introduction

Although the food supply of the United States is one of the most sanitary and inspected in the world, achieving absolute safety is neither possible nor practical. Food safety is improved as knowledge is gained about the prevalence of pathogens and the prevention of foodborne diseases (Buchanan and Deroever, 1993). Of all hazards associated with foods, the microbial hazard is the greatest, accounting for more than 90% of confirmed foodborne outbreaks and cases (Bean et al., 1990a, 1990b; see Table 5.1).

The environment, soil, plants, and animals are natural habitats of several foodborne pathogens. Microorganisms can be exchanged between these sources. The significance of and the potential hazard associated with the microorganisms depend on (1) type of food, (2) number of microorganisms present, (3) amount of food ingested, (4) treatment of food before consumption, and (5) susceptibility of consumer (adults versus babies or the elderly; the sick versus the healthy) (see Table 3.2). Many raw foods contain low levels of certain pathogens, and the hazards associated with such foods depend on the treatment that they receive before being consumed. The microbial flora of food products consists of the microorganisms associated with raw materials, those acquired during processing and handling, those surviving preservation treatments, and those multiplying during or surviving storage.

Several factors contribute to the increased concern about foodborne diseases, including (1) introduction of new food products with reduced levels of microbial inhibitors such as sodium chloride; (2) proliferation of ready-to-eat refrigerated convenience foods with an extended shelf life; (3) large, complex distribution channels; (4) potential for mishandling during final preparation and storage of prepared foods; and (5) consumer preference for undercooked or uncooked foods of animal origin.

Today, changing lifestyles and new technologies, e.g., modified atmosphere packaging and microwave cooking, have created a revolution in convenience foods. Shelf stable and frozen microwaveable entrees have been introduced, as have refrigerated *sous vide* foods—or foods vacuum sealed and usually cooked at temperatures less than 160°F, and both fresh meat and seafood packaged in a modified atmosphere. These factors may contribute to the vulnerability of food to survival and growth of pathogens if not appropriately applied.

When food processed by a large manufacturer is involved, the potential for a large-scale outbreak increases, as evidenced by the five-state outbreak of salmonellosis in milk in 1985 (Ryan et al., 1987). The food processing industry is involved in less than 10% of reported foodborne disease outbreaks of known origin (Bean and Griffin, 1990), with food from caterers, restaurants, and hospitals involved in about 70%, and food prepared at home contributing to about 20% of these outbreaks. Thus, the food handler plays an important role either in ensuring safety or enhancing risk.

Such statistics, however, present an incomplete picture of the foodborne disease problem. Pathogens including *Bacillus cereus*, *Clostridium perfringens*, *Listeria monocytogenes*, and others frequently are present on incoming raw (and sometimes heat processed) products of animal or vegetable origin. Outbreaks of salmonellosis may originate in contaminated animal feed ingested by food-source animals. Infection and contamination may be intensified during crowding on farms, transit to slaughterhouses,

and holding in pens. *Salmonella* is spread to carcasses and parts during processing. When the contaminated product enters the kitchen, further mishandling may occur.

Prevalence of Pathogens in Foods

Raw foods of animal origin frequently are contaminated with pathogens. The average consumer is unaware of the extent of such contamination. Even if a unit of food contains only a few microorganisms, many bacterial species can grow to large populations in a short time if the storage temperature is improper, e.g., if stew is improperly cooled and inadequately reheated. Raw foods may carry pathogens that are transferred later to other foods (processed, previously cooked, or those that will not be cooked at all); this is called cross-contamination. Furthermore, consumers typically are unaware that some foodborne pathogens such as *Listeria monocytogenes* or *Yersinia enterocolitica* can grow at refrigeration temperature, e.g., when raw foods or leftovers are stored for long periods in the refrigerator. Also, bacterial growth occurs when foods cool slowly during refrigerated storage.

The types of pathogens detected in certain raw foods are shown in Table 4.1. These data are intended to be representative but not inclusive of all data reported in the literature. Various foods are involved in foodborne illnesses, but animal foods (beef, pork, poultry, seafood, milk, and eggs) and their products are vehicles of more outbreaks than are others in the United States.

Salmonella is the pathogen known to be associated most frequently with foodborne disease in the United States and Canada. Foods of animal origin are the main vehicles for salmonellosis because animals often are carriers of *Salmonella*. A study of the prevalence of *Salmonella* in eviscerated chickens from chiller tanks in processing plants indicated that 20.5% of chickens were positive for the microorganism in 1969 (171 samples), compared with 11.6% in 1979 (215 samples) (Campbell et al., 1983). In contrast, a study by Green et al. (1982) demonstrated that in 1967 28.6% of eviscerated chickens (597 samples) from chiller tanks were contaminated with *Salmonella* and that in 1979 36.9% (601 samples) were.

Samples containing salmonellae from individual processing plants ranged from 7.5 to 73.7% in 1967 and from 2.5 to 87.5% in 1979 (Green et al., 1982). The most recent survey conducted by Green (1987) from 1982 to 1984 indicated that the incidence of *Salmonella* in whole broilers obtained from processing plants was 35.2%.

Staphylococcal intoxication is the second most commonly reported foodborne disease. Most outbreaks are associated with cooked meat and poultry products, e.g., sliced ham, beef, pork, and poultry, that are handled after cooking and then either left at room or outdoor temperature for several hours or improperly refrigerated, e.g., stored in large, deep containers (Table 4.1). Food handlers are the principal sources of *Staphylococcus aureus* involved in foodborne illness because *S. aureus* colonizes the nasal passage and skin of many healthy individuals.

Listeria monocytogenes is distributed widely in nature and has been isolated from a variety of foods including dairy products, vegetables, liquid whole egg, red meat, poultry, and seafood. *L. monocytogenes* was detected on from 0 to 70% of uncooked meat and poultry samples obtained from seven countries (Farber, 1993; Shelef, 1989).

Before the introduction of pasteurization, raw milk and milk products made from raw milk were the vehicles of many outbreaks; pasteurization greatly reduced the incidence of these illnesses (Bryan, 1983). Bryan (1988a) reported that dairy products account for less than 5% of all foodborne outbreaks. Raw milk is a source of many pathogens, including *Bacillus cereus, Campylobacter jejuni, Listeria monocytogenes, Salmonella* serovars, *Escherichia coli*, and *Yersinia enterocolitica*. The consumption of raw milk is hazardous, and the use of unpasteurized milk to manufacture dairy products must be controlled carefully to ensure safety. Because of the hazard, the sale of raw milk in the United States is not permitted except in a few locations today. A survey by D'Aoust (1989) indicated that 0 to 45% of raw milk samples from Canada, England, France, The Netherlands, Spain, and the United States were positive for *Bacillus cereus, Campylobacter jejuni, Listeria monocytogenes,* or *Salmonella* serovars.

A few surveys have demonstrated a high incidence of *Ascaris, Entamoeba histolytica, Escherichia coli*, and *Giardia lamblia* on market vegetables and fruits (Kowal, 1982). A survey of wholesale vegetables in the United States revealed *Salmonella* serovars and *Ascaris* in 2% of samples (Pude et al., 1984). In Italy and The Netherlands, respectively, 68 and 22% of lettuce and vegetables assayed were contaminated with *Salmonella* (Ercolani, 1976; Tamminga et al., 1978).

A variety of enteric viruses are responsible for GI diseases, hepatitis, and numerous other illnesses.

Table 4.1. Selected illustrations of the prevalence of pathogens or potential pathogens in foods in the United States and other countries

Organism	Food	Percent positive	Reference
Aeromonas hydrophila[a]	Seafood	19–100	Abeyta, 1983; Abeyta et al., 1989; Colburn et al., 1989; Fricker and Tompsett, 1989; Palumbo et al., 1985
	Raw milk	33	Palumbo et al., 1985
	Poultry	16–100	Barnhart et al., 1989; Fricker and Tompsett, 1989; Palumbo et al., 1985; Ternstrom and Molin, 1987
	Red meats	100	Palumbo et al., 1985
	Cooked meats	10	Fricker and Tompsett, 1989
	Pork	6–27	Fricker and Tompsett, 1989; Ternstrom and Molin, 1987
	Beef	11–33	Fricker and Tompsett, 1989; Ternstrom and Molin, 1987
	Produce	95	Callister and Agger, 1987
Aeromonas species[a]	Lamb	59	Marjeed et al., 1989
Anisakid nematodes	Marine and anadromous fish	0–100	Myers, 1979
Bacillus cereus	Pork	4–7	Konuma et al., 1988; Ternstrom and Molin, 1987
	Beef	11–63	Konuma et al., 1988; Ternstrom and Molin, 1987
	Chicken	0–7	Sooltan et al., 1987; Ternstrom and Molin, 1987; Weagant et al., 1988
	Meat additives	39	Konuma et al., 1988
	Raw milk	9	Ahmed et al., 1983
	Pasteurized milk	35	Ahmed et al., 1983
	Dairy products	0–63	Ahmed et al., 1983; Mosso et al., 1989; Rodriguez and Barrett, 1986
	Raw rice	100	Bryan et al., 1981
	Pasta and flour	0	Mosso et al., 1989
	Seafood	1	Abeyta, 1983
Campylobacter (thermophilic)	Pork carcasses	17	Lammerding et al., 1988
	Beef carcasses	23	Lammerding et al., 1988
	Veal carcasses	43	Lammerding et al., 1988
	Turkey carcasses	74	Lammerding et al., 1988
	Chicken carcasses	38	Lammerding et al., 1988
Campylobacter coli	Pork carcasses	13	Bracewell et al., 1985
Campylobacter jejuni	Pork	0–24	Mafu et al., 1989; Stern et al., 1984; Ternstrom and Molin, 1987
	Beef carcasses	50	Garcia et al., 1985
	Beef	0–5	Gill and Harris, 1984; Stern et al., 1984; Ternstrom and Molin, 1987
	Lamb	1–20	Stern et al., 1984
	Turkey	56–64	Rayes et al., 1983
	Chicken	8–89	Christopher et al., 1982b; Kinde et al., 1983; Norberg, 1981; Shanker et al., 1982; Stern et al., 1984; Ternstrom and Molin, 1987
	Raw milk	0.4–1.2	Davidson et al., 1989; Doyle and Roman, 1982; McManus and Lanier, 1987
	Fresh mushrooms	2	Doyle and Schoeni, 1986
Clostridium botulinum	Bacon	0.1	Hauschild and Hilsheimer, 1980
	Liver sausage	2	Hauschild and Hilsheimer, 1983
	Infant foods	0	Kautter et al., 1982
	Corn syrup	20	Kautter et al., 1982
	Honey	2	Kautter et al., 1982
Clostridium perfringens	Pork	0–39	Bauer et al., 1981; Ternstrom and Molin, 1987
	Cooked pork	45	Kokubo et al., 1986
	Beef	22	Ternstrom and Molin, 1987
	Chicken	0–54	Lillard et al., 1984; Ternstrom and Molin, 1987
	Seafoods	2.4	Abeyta, 1983

Table 4.1. (continued)

Organism	Food	Percent positive	Reference
Enterovirus	Shellfish	0–47.8	Ellender et al., 1980; Gerba and Goyal, 1978; Goyal et al., 1979; Khalifa et al., 1986; Vaughn et al., 1980; Wait et al., 1983
Escherichia coli (enterotoxigenic)	Cheese	0	Glatz and Brudvig, 1980
	Raw milk	0	Glatz and Brudvig, 1980
Escherichia coli O157:H7	Raw beef kidneys	0.1–0.5	Griffin and Tauxe, 1993
	Beef	3.7	Doyle and Schoeni, 1987
	Pork	1.5	Doyle and Schoeni, 1987
	Poultry	1.5	Doyle and Schoeni, 1987
	Lamb	2	Doyle and Schoeni, 1987
Escherichia coli (verotoxigenic)	Raw beef	17	Willshaw et al., 1993
	Ground beef	36.4	Read et al., 1990
	Ground pork	10.6	Read et al., 1990
	Mechanically separated chicken	0	Read et al., 1990
Listeria monocytogenes	Raw red meats	0–43	Buchanan et al., 1989; Ternstrom and Molin, 1987
	Ground beef	77	Farber et al., 1988
	Ground pork	95	Farber et al., 1988
	Ground veal	100	Farber et al., 1988
	Chicken	13–56	Bailey et al., 1989; Farber et al., 1988; Genigeorgis et al., 1989
	Turkey	12–18	Genigeorgis et al., 1990
	Cured meats and fermented sausages	0–20	Buchanan et al., 1989; Farber et al., 1989; Trussel, 1989
	Seafood	11–26	Buchanan et al., 1989; Weagant et al., 1988
	Raw milk	1.6–4.2	Davidson et al., 1989; Farber and Peterkin, 1991; Liewen and Plautz, 1988; Lovett et al., 1987
	Pasteurized milk	0	Farber et al., 1988
	Ice cream	0.25	Farber et al., 1988
	Raw whole egg	5	Leasor and Foegeding, 1989
	Produce and vegetables	0	Farber et al., 1989
Salmonella serovars	Beef	0–2.6	Lammerding et al., 1988; Ternstrom and Molin, 1987
	Veal carcasses	4.1	Lammerding et al., 1988
	Pork	0–18	Genigeorgis et al., 1989; Lammerding et al., 1988; Madden et al.,1986a; Ternstrom and Molin, 1987
	Pork products	3–20	Duitschaever and Buteau, 1979; Farber et al., 1988
	Turkey carcasses	69	Lammerding et al., 1988
	Turkey sausage	100	Duitschaever and Buteau, 1979
	Chicken	0–100	Duitschaever and Buteau, 1979; Izat et al., 1989; Lammerding et al., 1988; Lillard et al., 1984; Norberg, 1981; Ternstrom and Molin, 1987
	Shellfish	3.7–33	Colburn et al., 1989; Fraiser and Koburger, 1984
	Fish	0	Fraiser and Koburger, 1984
	Raw milk	0.5–4.7	McEwen et al., 1988; McManus and Lanier, 1987
Staphylococcus aureus	Raw beef	16	Ternstrom and Molin, 1987
	Raw pork	13	Ternstrom and Molin, 1987
	Pork sausage	33	Farber et al., 1988
	Raw chicken	41–73	Lillard et al., 1984; Ternstrom and Molin, 1987
	Seafood	38	Abeyta, 1983
	Bakery items[b]	9.8	Sumner et al., 1993
Vibrio cholerae	Shellfish	7.4–33	Colburn et al., 1989; Tepedino, 1982

Table 4.1. (continued)

Organism	Food	Percent positive	Reference
Vibrio parahaemolyticus	Seafood	2.8–46	Abeyta, 1983; Hackney et al., 1980
Yersinia enterocolitica[c]	Beef	2	Ternstrom and Molin, 1987
	Pork	2.5–49	Genigeorgis et al., 1989; Schiemann, 1980; Ternstrom and Molin, 1987
	Processed pork products	7–37	Delmas and Vidon, 1985; Schiemann, 1980
	Chicken	11–25	Norberg, 1981; Ternstrom and Molin, 1987
	Raw milk	2.7–48	Davidson et al., 1989; McManus and Lanier, 1987; Moustafa et al., 1983
	Pasteurized milk	1	Moustafa et al., 1983
	Ice cream	22	Delmas and Vidon, 1985
	Raw vegetables	46	Delmas and Vidon, 1985

[a]It was not shown that the *Aeromonas* isolates were pathogenic for humans.
[b]Oatmeal raisin cookies, apple muffins, cream puffs, long johns.
[c]Many strains of *Yersinia enterocolitica* isolated from foods are avirulent.

Although there are more than 100 different types of viruses, studies of their occurrences in food are limited because methods for their detection on a routine basis are unavailable.

Fish, shellfish, and crabs living in water contaminated by sewage frequently contain enteric bacteria and viruses (Table 4.2; Eastaugh and Shepherd, 1989). Additionally, laboratory studies have demonstrated that lobsters, sandworms, detrital feeding fish, conch, and aplysia can accumulate enteric viruses (Gerba and Goyal, 1978; Metcalf, 1976; Sigel et al., 1976). Only shellfish, however, have been implicated in the transmission of enteric viral illness, probably because they often are eaten raw or are cooked less thoroughly than other seafoods. Bivalve mollusks sieve out suspended food particles from a current of water passing through the shell cavity and tend to concentrate viruses from the water in which they are growing. Hence, viruses may occur in shellfish at a concentration much higher than that of the surrounding water.

Occurrence of enteroviruses in shellfish harvested from the coastal waters of the United States has been well documented (Ellender et al., 1980; Gerba and Goyal, 1978; Goyal et al., 1979; Vaughn et al., 1980; Wait et al., 1983). In each of these studies, enteroviruses were isolated from areas open to shellfish harvesting. Viral concentrations ranged from 10 to 200 viral units per 100g of shellfish. Percentages of virus-positive shellfish ranged from 9 to 40 for open waters and from 13 to 40 for closed waters (Fugate et al., 1975). No statistically significant relationship has been detected between concentrations of enteric viruses and either coliform or fecal coliform bacteria, which are used as indicators of fecal pollution in shellfish or in shellfish-growing waters (Goyal et al., 1979; Wait et al., 1983). Whereas a variety of marine animals are capable of accumulating enteric viruses when placed in virus contaminated marine waters, field studies have demonstrated the presence of enteric viruses in only one marine animal—namely the blue crab—other than shellfish. The animal was from a sludge dump-site in the North Atlantic (Goyal, 1984).

Table 4.2. Factors enhancing shellfish-transmitted viral disease

Bivalve mollusks are filter feeders and can concentrate viruses from contaminated water and sediment.
Viruses can survive inside the shellfish.
Tests of bacteria (fecal coliforms) used to assess the pollution level of water or shellfish do not relate directly to viral contamination.
Exposure to one virus particle may cause an infection although the probability of infection by one particle is small.
Bivalve mollusks often are eaten raw.
Viruses can survive insufficient cooking and steaming processes.

Growth and Survival of Pathogens and Persistence or Destruction of Toxins in Foods

Clearly, most raw foods can be contaminated with pathogens and can cause disease if ingested raw, improperly cooked, or otherwise mishandled, e.g., cross-contaminated. If properly processed and handled, however, these foods can be made safe. Under the right conditions, even one bacterial pathogen per unit of food can increase to populations capable of causing foodborne illness if perishable food is not refrigerated or is refrigerated improperly. Certain microorganisms in foods produce toxins that, in the case of staphylococcal enterotoxins for instance, are resistant to boiling.

Although viruses and parasites will not grow in foods, these infectious agents can persist there, and the presence of small populations (1 to 10) of a virus or a parasite may be sufficient to cause infection for some individuals.

Metabolism and growth of pathogenic microorganisms in foods are affected by amount and type of nutrient available in food, water activity (a_w), pH, oxygen availability, temperature, and time. Under optimal conditions, certain pathogens reproduce about every 15 to 30 minutes. If stress, e.g., heat, low a_w, low temperature, or acid condition, is applied, microorganisms may fail to survive or may not grow. Survival and growth conditions for various foodborne pathogens are presented in Table 4.3.

Processed foods may be subjected to treatments that kill pathogens, e.g., pasteurization, sterilization, acidification, preservation, reduced water activity, low-temperature storage (refrigeration or freezing), and modified atmosphere storage. Because a single barrier often is insufficient to ensure food safety, a combination of several barriers may be used (Jackson et al., 1991).

Foods suitable for human consumption also often are suitable growth media for most bacterial foodborne pathogens, and bacteria can grow in food if their temperature requirements are met. Bacteria such as *Aeromonas hydrophila*, *Clostridium botulinum* type E, *Listeria monocytogenes*, and *Yersinia enterocolitica* can multiply at refrigeration temperature. Other pathogens can grow if food is subjected to time-temperature abuse. The data in Table 4.3 indicate that once a cooked food has been contaminated with a bacterial pathogen, the microorganism may survive and, under the right conditions, multiply.

Long-term frozen storage generally leads to a decrease but not to an elimination of bacterial pathogens. When frozen foods are subjected to warm temperatures, growth usually occurs (Table 4.3). Again, it should be emphasized that viruses and parasites do not grow in foods, yet at refrigerated and frozen temperatures these microorganisms can survive for many months. At room temperature, viruses and parasites can survive in foods for weeks. Freezing is not an effective method of killing bacteria although it kills parasites if held for sufficient time. Thus, if a population of bacterial or viral pathogens is present in foods, a portion of the population is likely to survive refrigeration and freezing.

The most common method of killing microorganisms is to subject them to heat, for most microbial pathogens are susceptible to high temperatures. Some bacterial toxins and some viruses such as HAV are at least moderately heat stable (Feingold, 1973). *Staphylococcus aureus* enterotoxin will survive boiling (212°F) and higher temperatures (250°F).

Food production, processing, preparation, and storage may increase or decrease the likelihood of exposure to foodborne pathogens. Thorough investigations of foodborne disease outbreaks identify factors contributing to food contamination, to contaminant survival, and to bacterial growth. The frequency of occurrence of these factors provides an excellent indication of risks and possible control points. Both factors contributing to foodborne illness outbreaks and controls possibly preventing foodborne illness are discussed in Chapter 7.

Table 4.3. Survival and growth of pathogens or potential pathogens in foods

Organism	Food	Fate	Reference
Aeromonas hydrophila[a]	Retail chicken, red meat, seafood	G, 7 d, 5°C	Palumbo et al., 1985
	Cooked fish mince and surimi	G, 27 h–5 d, 5–25°C	Ingham and Potter, 1988
	Produce	G, 6–14 d, 4–15°C	Berrang et al., 1989; Callister and Agger, 1987
Bacillus cereus	Pasteurized milk	G, 24 h, 30°C	Wong et al., 1988
	Fermented milk (spores)	K, 24 h, 30°C	Wong et al., 1988
	Fermented milk (vegetable cells)	NG, 24 h, 30°C	Wong et al., 1988
	Ground beef	NG, 5–14 d, 1–12.5°C	Goepfert and Kim, 1975
	Pumpkin pie	G, 48 h, 25°C	Wyatt and Guy, 1981b
Campylobacter jejuni	Ground beef	K or NG, 3–30 d, – 15–20°C	Christopher et al., 1982b; Koidis and Doyle, 1983; Stern and Kotula, 1982
	Chicken	K, 18–24 d , 4–23°C	Blankenship and Craven, 1982
	Turkey roll or ham	K, 14 d, 4°C	Reynolds and Draughon, 1987
	Raw egg yolk	G, 24 h, 42°C	Clark and Bueschkens, 1986
	Raw egg white	K, 24 h, 42°C	Clark and Bueschkens, 1986
	Sterile skim milk	K, 2–14 d, – 20–20°C	Christopher et al., 1982a
	Cheddar cheese manufactured	K, 30–60 d, 7°C	Ehlers et al., 1982
	Cottage cheese manufactured	K, 0.5 h, 55°C	Ehlers et al., 1982
Clostridium botulinum	Hamburger sandwich (O_2)	toxin, 7 d, 25°C	Kautter et al., 1981
	Hamburger sandwich (N_2)	toxin, 4 d, 25°C	Kautter et al., 1981
	Sausage sandwich (O_2)	no toxin, 7 d, 25°C	Kautter et al., 1981
	Sausage sandwich (N_2)	toxin, 21 d, 25°C	Kautter et al., 1981
	Baked potato	toxin, 3–7 d, 22–30°C	Sugiyama et al., 1981
	Tofu	no toxin, 6 w, 5–10°C	Kovats et al., 1984
	Tofu	toxin, 2–3 w, 15–25°C	Kovats et al., 1984
Clostridium perfringens	Beef patties, cooked in microwave to 60–65°C, 65–71°C, or 71–77°C	G, 24 h, 27°C	Wright-Rudolf et al., 1986
Escherichia coli O157:H7	Raw beef patties	NG, 9 m, – 20°C	Doyle and Schoeni, 1984
Listeria monocytogenes	Ground beef	NG, 15–25 d, 4°C	Johnson et al., 1988a; Shelef, 1989
	Beef liver	NG, 40 d, 4°C	Shelef, 1989
	Chicken breast, cooked[b]		
	76.7 or 82.2, O_2 or vac	G, 4 w, 4°C	Harrison and Carpenter, 1989
	76.7 or 82.2, O_2	G, 10 d, 10°C	Harrison and Carpenter, 1989
	76.7 or 82.2, vac	G, 10 d, 10°C	Harrison and Carpenter, 1989
	Finnish fermented sausage	NG, 21 d, 10°C	Junttila et al., 1989
	Fermented sausage	K, 8–12 w, 4°C	Glass and Doyle, 1989b; Johnson et al., 1988b
	Summer sausage	NG, 12 w, 4.4°C	Glass and Doyle, 1989a
	Various cured meat products	G, 2–4 w, 4.4°C	Glass and Doyle, 1989a
	Sliced cooked poultry	G, 2 w, 4.4°C	Glass and Doyle, 1989a
	Roast beef	G, 6 w, 4.4°C	Glass and Doyle, 1989a
	Milk products	G, 25 h–50 d, 4–35°C	Rosenow and Marth, 1987
	Nonfat dry milk	K, 16 w, 25°C	Doyle et al., 1985
	Cottage cheese	K, 28 d, 3°C	Ryser et al., 1985
	Brick cheese	G, 26 w, 10°C	Ryser and Marth, 1989
	Colby cheese	G, 140 d, 4°C	Yousef and Marth, 1988
	Blue cheese	K, 120 d, 4°C	Papageorgiou and Marth, 1989a
	Cheddar cheese	K, 434 d, 3°C	Ryser and Marth, 1987a
	Feta cheese	G, 65 d, 4°C	Papageorgiou and Marth, 1989b
	Camembert cheese	G, 65 d, 6°C	Ryser and Marth, 1987b
	Raw whole egg	NG, 22 d, 5°C	Sionkowski and Shelef, 1990
	Raw whole egg	K, 80 h, 20°C	Sionkowski and Shelef, 1990
	Raw egg albumin	K, 80 h–22 d, 5–20°C	Sionkowski and Shelef, 1990
	Raw egg yolk	G, 80 h–22 d, 5–20°C	Sionkowski and Shelef, 1990
	Meat, egg, or cheese ravioli	NG, 14 d, 5°C	Beuchat and Brackett, 1989
	Head lettuce	G, 14 d, 5–25°C	Steinbruegge et al., 1988

Table 4.3. (continued)

Organism	Food	Fate	Reference
Poliovirus	Shellfish	Survived, 10 d, 4–25°C	Eyles, 1983; Gerba and Goyal, 1978
	Clams	Survived cooking	DiGirolamo et al., 1970
	Lettuce	Survived, 14–300 d, −20–5°C	Bachacy et al., 1985
Salmonella anatum, chester, havana, poona, senftenberg	Cantaloupe	G, 23°C, 24 h NG, 5°C, 24 h	Golden et al., 1993
	Watermelon	G, 23°C, 24 h NG, 5°C, 24 h	Golden et al., 1993
	Honeydew melons	G, 23°C, 24 h NG, 5°C, 24 h	Golden et al., 1993
Salmonella enteritidis	Italian salad dressing, egg added	K, 0.12 h, 25°C	Miller and Martin, 1990
Salmonella montevideo and *heidelberg*	Dry milk	K, 14 w, 25°C	Juven et al., 1984
Salmonella newport	Cooked meat balls	G, 6 h, 23°C	Stern and Custer, 1985
Salmonella typhi	Watermelon	G, 24 h, 22°C	Escartin et al., 1989
Salmonella typhimurium	Cooked meat balls	G, 6 h, 23°C	Stern and Custer, 1985
	Chicken salad	G, 24 h, 4–32°C	Doyle et al., 1982
	Ham salad	NG, 24 h, 4°C	Doyle et al., 1982
	Ham salad	G, 24 h, 22–32°C	Doyle et al., 1982
	Tofu	K, 14 d, 5°C	Kovats et al., 1984
	Tofu	G, 24 h–7 d, 15–25°C	Kovats et al., 1984
	Pumpkin pie	K, 84 h, 4°C	Wyatt and Guy, 1981a
	Pumpkin pie	G, 48 h, 25–35°C	Wyatt and Guy, 1981a
	Italian salad dressing, egg added	K, 0.12 h, 25°C	Miller and Martin, 1990
Shigella flexneri and *dysenteriae*	Papaya	G, 6 h, 25–27°C	Escartin et al., 1989
Shigella sonnei	Papaya	G, 6 h, 25–27°C	Escartin et al., 1989
	Shredded lettuce	NG, 3 d, 5–15°C	Davis et al., 1988
	Shredded lettuce	G, 12 h, 22°C	Davis et al., 1988
Staphylococcus aureus	Raw turkey meat	NG, 5 d, 7–10°C	Yang et al., 1988
	Raw turkey meat	G, 5 d, 15–20°C	Yang et al., 1988
	Chicken salad	NG, 24 h, 4°C	Doyle et al., 1982
	Chicken salad	G. 24 h, 22–32°C	Doyle et al., 1982
	Ham salad	NG, 24 h, 4–22°C	Doyle et al., 1982
	Ham salad	G, 24 h, 32°C	Doyle et al., 1982
	Canned salmon, N_2, air or O_2 headspace	G, 4 d, 22°C	Stersky et al., 1986
	Cooked fish mince and surimi	NG, 5 d, 5°C	Ingham and Potter, 1988
	Cooked fish mince and surimi	G, 27 h, 25°C	Ingham and Potter, 1988
	Tofu	K, 6 w, 5°C	Kovats et al., 1984
	Tofu	G, 24 h, 5–25°C	Kovats et al., 1984
	Pumpkin pie	K, 84 h, 4°C	Wyatt and Guy, 1981a
	Pumpkin pie	G, 48 h, 25–35°C	Wyatt and Guy, 1981a
	Bakery items[c]	K, 24h, 25°C	Sumner et al., 1993
	Cream puff fillings	G, 24h, 25°C	Sumner et al., 1993
Vibrio parahaemolyticus	Cooked fish mince and surimi	K, 48 h, 5°C	Ingham and Potter, 1988
	Cooked fish mince and surimi	G, 48 h, 25°C	Ingham and Potter, 1988
Vibrio vulnificus	Oysters	K, 24 h–8 d, 0.5–4°C	Kaysner et al., 1989; Oliver, 1981

Table 4.3. (continued)

Organism	Food	Fate	Reference
Yersinia enterocolitica[d]	Raw shrimp	K, 60 d, – 20°C	Peixotto et al., 1979
	Raw shrimp	K or NG, 21 d, 1–5°C	Peixotto et al., 1979
	Shucked oysters	G, 14 d, 0–7°C	Peixotto et al., 1979
	Cooked crab meat	K, 14 d, 1°C	Peixotto et al., 1979
	Cooked crab meat	G, 14 d, 5°C	Peixotto et al., 1979
	Tofu	G, 24 h–14 d, 5–25°C	Kovats et al., 1984
	Pasteurized skim milk	G, 21 d, 4°C	Amin and Draughon, 1987
	Yogurt	K, 7 d, 5°C	Ahmed et al., 1986

[a]It was not shown that the *Aeromonas* isolates were pathogenic for humans.
[b]In the chicken breast experiments, cooking reduced count from 10^7 to 10^1 colony forming units (CFU)/g.
[c]Oatmeal raisin cookies, apple muffins, cream puffs, long johns.
[d]Many strains of *Yersinia enterocolitica* isolated from foods are avirulent.

Abbreviations:
G = growth
NG = no growth, organisms survived
K = killing occurred but may have survivors
h = hours
d = days
w = weeks
m = months
°C = degrees centigrade
vac = vacuum packaged

5 Risk Characterization: Estimated Numbers of Illnesses and Deaths

The estimated number of acute foodborne disease cases occurring in the United States is determined with difficulty, and various estimates exist. Comprehensive estimates of the number of human illnesses caused by many foodborne microorganisms are unavailable; those that are available frequently provoke controversy. This chapter identifies and evaluates selected data sources containing foodborne disease estimates. Plausible estimates from the literature regarding number of U.S. cases of acute illness caused by specific foodborne microorganisms are summarized. The general consensus of the CAST task force members is that cases likely range from 6.5 million to 33 million annually and that deaths may be as high as 9,000 annually. Chronic disease sequelae as a result of exposure to foodborne pathogens are less well understood, and estimates have been attempted for only a few chronic foodborne disease sequelae.

Sources of Data on Acute Foodborne Illnesses

Data sources include (1) foodborne disease reports collected by the CDC[1] under its various programs, (2) national hospital databases or health surveys in which intestinal diseases are reported, (3) risk models based on infectious doses and on pathogens' prevalence in foods, and (4) experts' extrapolations to estimate number of foodborne disease cases and distribution of disease severities.

[1]The CDC was established in 1973 as an operating health agency within the Public Health Service and is composed of 10 major operating components. It is the federal agency charged with protecting the public health of the nation by providing leadership and direction in the prevention and control of diseases and other preventable conditions and by responding to public health emergencies. In 1993, the name was changed to the Centers for Disease Control and Prevention.

CDC Foodborne Outbreak Data

The CDC outbreak data rely on reports from state and local health departments that have received information from two or more[2] individuals experiencing a similar illness, have conducted an investigation identifying food as the common source, and have notified the CDC (Figure 5.1). A great variety of diseases are reported including some, such as ciguatera and scombroid poisoning, that are diagnosed without laboratory testing (Table 5.1). Because tests for the most common foodborne disease pathogens are the most likely to be ordered, reports contain information primarily on these microorganisms; in theory, however, outbreaks caused by any pathogenic microorganisms should be reported. Reports also are limited by the ability of state and local health departments to follow up leads and to report investigations to the CDC. Typically, budget constraints impede thorough investigation, and outbreaks involving restaurants or institutions are more likely to be recognized than those involving homes or processed foods. This difference exists because of the greater numbers of individuals served by a commercial kitchen at any one mealtime and perhaps also because of the health department's responsibility to protect consumers from commercial sources and processed foods.

Data differ widely by state and reflect, for the most part, the vigilance of health departments and their priorities for food safety (Bartelson, 1987; Chalker and Blaser, 1988). The Council of State and Territorial Epidemiologists pointed out that final decisions regarding foodborne disease surveillance are made by each state and that 12 of the states have no surveillance staff specifically assigned to monitoring food associated or waterborne pathogens; in other words, outbreaks will not be reported routinely from these states (Berkelman et al., 1994). Typically, 400 to 500 foodborne outbreaks are reported annually to the CDC, with an average of about 40 cases per outbreak, for an average of about 18,000 foodborne disease cases

[2]For botulism, toxic fish, mushroom, and certain chemical poisonings, one case constitutes an outbreak.

annually (Table 5.1).

CDC Laboratory-Based Surveillance Data

The CDC laboratory-based surveillance data are reported by state laboratories identifying microorganisms as causes of human illness. The CDC has laboratory-based surveillance systems for a number of foodborne[3] diseases: botulism, campylobacteriosis, cholera, hepatitis A, listeriosis, salmonellosis, shigellosis, trichinosis, and typhoid fever. Around 44,000 nontyphoidal salmonellosis cases[4], 20,000 shigellosis cases, and 10,000 campylobacteriosis cases are reported annually to the CDC (Bean and Griffin, 1990). The

[3]These data do not show the percentage of foodborne cases (except for trichinosis, which always is foodborne). Typhoid fever, nontyphi salmonellosis, cholera, hepatitis A, and shigellosis can be transmitted by water and by person-to-person spread (fecal-oral), as well as by food. Infant botulism may be soil/dustborne. Salmonellosis has been transmitted through the hospital environment. Hence, all such laboratory data cannot be judged as exclusively foodborne.

[4]Some positive laboratory tests, especially those for *Salmonella* serovars and *Shigella* spp., are for carriers of the disease, not for actual cases of illness.

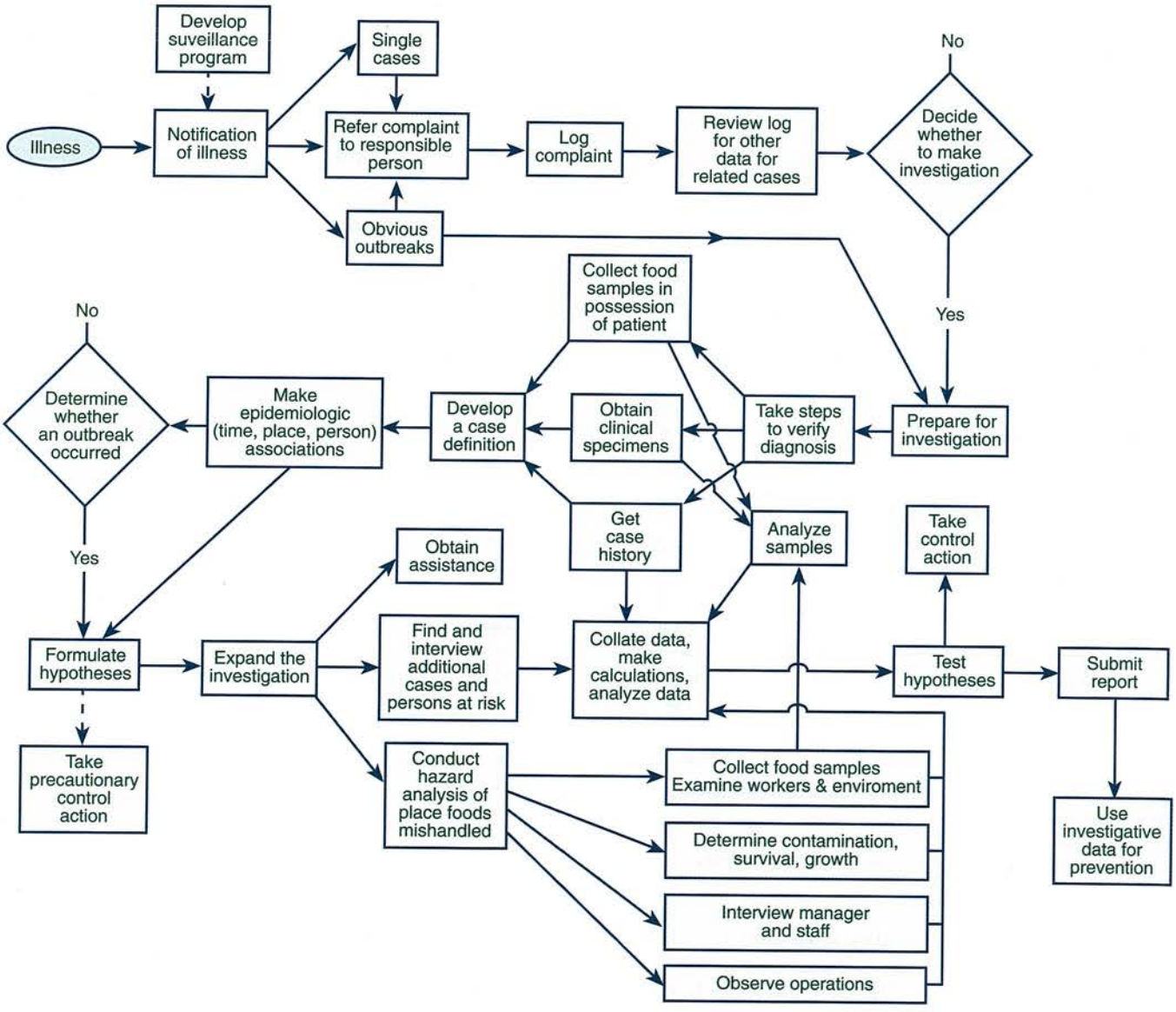

Figure 5.1. Sequential events in investigating a typical outbreak of foodborne illness (Bryan et al., 1987).

Table 5.1. Annual average numbers of foodborne disease outbreaks, cases, and deaths, by etiologic agent reported to CDC[a]

	Outbreaks[b]		Cases		Deaths	
Etiologic agent	Number	%	Number	%	Number	%
Bacterial						
Bacillus cereus	3.2	1.8	52	0.5	0.0	0.0
Brucella	0.4	0.2	8	0.1	0.2	0.7
Campylobacter	5.6	3.1	145	1.3	0.2	0.7
Clostridium botulinum	14.8	8.1	28	0.3	2.0	7.3
Clostridium perfringens	4.8	2.6	549	4.9	0.4	1.5
Escherichia coli	1.4	0.8	128	1.2	0.8	2.9
Salmonella	68.4	37.6	6,249	56.3	7.8	28.5
Shigella	8.8	4.8	1,994	18.0	0.6	2.2
Staphylococcus aureus	9.4	5.2	636	5.7	0.0	0.0
Streptococcus, Group A	1.4	0.8	200	1.8	0.0	0.0
Streptococcus, other	0.4	0.2	17	0.2	0.6	2.2
Vibrio cholerae	0.2	0.1	0	0.0	0.0	0.0
Vibrio parahaemolyticus	0.6	0.3	2	0.0	0.0	0.0
Other bacterial	0.6	0.3	52	0.5	14.0	51.1
Total	120.0	66.0	10,061	90.6	26.4	96.4
Chemical						
Ciguatoxin	17.2	9.5	66	0.6	0.0	0.0
Heavy metals	2.6	1.4	35	0.3	0.0	0.0
Monosodium glutamate	0.4	0.2	1	0.0	0.0	0.0
Mushroom poisoning	2.8	1.5	10	0.1	0.4	1.5
Scombrotoxin	16.6	9.1	61	0.6	0.0	0.0
Paralytic shellfish poisoning	0.4	0.2	1	0.0	0.0	0.0
Other chemical	6.2	3.4	74	0.7	0.2	0.7
Total	46.4	25.5	249	2.2	0.6	2.2
Parasitic						
Giardia lamblia	0.6	0.3	8	0.1	0.0	0.0
Trichinella spiralis	6.6	3.6	32	0.3	0.2	0.7
Total	7.2	4.0	41	0.4	0.2	0.7
Viral						
Hepatitis A virus	5.8	3.2	213	1.9	0.2	0.7
Norwalk virus	2.0	1.1	233	2.1	0.0	0.0
Other viral	0.4	0.2	112	1.0	0.0	0.0
Total	8.2	4.5	558	5.0	0.2	0.7
Confirmed agent	182.0	100.0	11,108	100.0	27.4	100.0
Unknown agent	290.0	NA[c]	7,228	NA	NA	NA
Total	480.0	NA	18,336	NA	27.4	NA

[a]The published numbers that were comprehensive for the 5-year period, 1983–1987, are presented here as one-year averages.
[b]Outbreak is two or more cases except for botulism and chemical cases.
[c]NA = not applicable.
Sources: Bean and Griffin, 1990; Bean et al., 1990a, 1990b.

laboratory-based surveillance data also are likely to be nationally representative of patients ill enough to seek medical attention although the distribution of illness severities will be unknown without additional survey efforts. Some states report more complete results to the CDC than do others. This difference is largely a function of funding provided by states to their health departments.

CDC Sentinel County Studies

Sentinel county studies sometimes are undertaken by the CDC for a specific pathogen. These investigations typically have a specific goal such as identifying the number of foodborne disease cases caused by a pathogen, e.g., *Listeria monocytogenes*, identifying virulence mechanisms, discovering potential food vehicles, or identifying severity distribution across cases. In recent sentinel county studies, data were collected on *Campylobacter*, *Listeria*, *Salmonella*, and *Shigella*. These sentinel county studies are a sample of selected counties, and more data, e.g., information about disease severity, are collected than under the passive foodborne data collection system. The sentinel studies, however, are not conducted annually and have been used for only a few pathogens because they are time consuming and expensive.

In 1979 and 1984, the CDC conducted sentinel county studies of reported salmonellosis cases in a representative sample of counties (Cohen and Tauxe, 1986). In both years, roughly 40,000 salmonellosis cases were confirmed by laboratory tests. Based on the survey, more than 22,000 people consulted a physician but were not hospitalized; 18,000 were hospitalized; and 500 died. But these 40,000 cases represent only a fraction of the total number of salmonellosis illnesses. Cohen and Tauxe (1986) stated that "only 1 to 10% of actual cases are reported," which suggests that between 400,000 and 4,000,000 salmonellosis cases occur annually. Adjusting for the undercounted cases by doubling the number of people in each severity category, Tauxe estimated 1,000 deaths, 36,000 hospitalizations, and 44,000 cases who only saw a physician. The remaining 1,919,000 cases were assumed to be mild (Table 5.2; Roberts, 1988).

Summary of Data Sources

The most comprehensive CDC data, in terms of the causes of foodborne illness, come from outbreak data (Table 5.1), but these include many fewer cases than do laboratory surveillance data. For example, for 1983 to 1987, 6,249 salmonellosis cases per year were reported in the outbreak data compared with 44,000 cases per year in the laboratory surveillance data (Table 5.2). Bennett et al. (1987) estimated that 96% of salmonellosis cases were foodborne.[5]

Medical Data Indicating Infection by Foodborne Microorganisms

Several types of medical data may illuminate either the number of cases of illness or the type of diseases caused by foodborne microorganisms. Autopsy data indicated that 100,000 Americans were exposed to trichinosis annually in the early 1970s (Zimmerman et al., 1973) although the distribution of symptomatic and asymptomatic infection and the relevance to exposure today are unclear. Epidemiologic reports, however, show that there is decreasing incidence of this disease in the United States. Antibod-

[5]Some CAST task force members think this estimate may be a little high because salmonellosis also is spread through contact with reptiles and amphibians and through person-to-person transmission.

Table 5.2. Salmonellosis data from Centers for Disease Control (CDC) sources, number of annual cases

	Outbreak data[a], 1983–1987	Laboratory surveillance data, 1990[b]	Sentinel county studies[c], 1979 and 1984	Extrapolations based on	
				Outbreak data[d]	Special surveillance studies[c, d]
Outbreaks	68	NA[e]	NA	NA	NA
Cases	6,249	44,000	40,000	2,000,000	400,000–4,000,000
Severity					
Deaths	8	ND[f]	500	2,000	1,000
Hospitalization	ND	ND	18,000	34,000	36,000
Physician seen	ND	ND	22,000	101,000	44,000
No medical attention	ND	NA	NA	1,863,000	1,919,000

[a]Bean et al., 1990a, 1990b.
[b]Bean and Griffin, 1990.
[c]Cohen and Tauxe, 1986.
[d]Roberts, 1989.
[e]NA = not applicable.
[f]ND = not done.

ies in blood show that roughly one-half the population is exposed to toxoplasmosis in their lifetimes (Frenkel, 1973), but few develop frank disease. Studies of *Listeria* carriage in feces indicate that at a minimum, 1 to 12% of the population becomes exposed annually (Armstrong, 1985). Whether these data for trichinosis, toxoplasmosis, or *Listeria* carriage indicate foodborne exposure or disease is unclear. Most exposures may be mild enough that the body successfully fights off the microorganisms and the person never is considered ill. Or it may be that a person experiences mild flu like symptoms, or perhaps more severe symptoms, without realizing their foodborne cause.

Studies of groups of ill persons are useful for identifying new pathogens, quantifying the relative prevalence of intestinal pathogens by means of investigating a clearly defined group of persons, or identifying new medical complications. The relative prevalences of salmonellosis, campylobacteriosis, shigellosis, and *Escherichia coli* O157:H7 infection were investigated for a health maintenance organization in the Seattle (King County) area (MacDonald et al., 1988). Smith and Blaser (1985) discovered two deaths of healthy people from campylobacteriosis—previously thought to be a relatively mild foodborne disease unless old age, infancy, or underlying disease impaired the immune system. Obtaining national illness estimates is difficult when generalizing from the limited group of individuals in a study.

One approach useful in calculating total estimates of foodborne disease is the analysis of health surveys.[6] Garthright et al. (1988) estimated that 99 million acute cases of *intestinal infectious disease*, defined as vomiting and/or diarrhea without respiratory symptoms, occur each year in the United States. In half the cases, the illnesses caused more than a day of restricted activity. A physician consultation occurred in only 8.2 million cases. Hospitalization occurred in 250,000. No attempt was made to estimate deaths (see Chapter 6 and Table 6.2 for cost estimates of medical expenses and lost productivity).

Although the fraction of total intestinal infectious disease cases that are foodborne is uncertain, an earlier paper by Garthwright's coauthors, Archer and Kvenberg (1985), suggested that 30 to 35% of these intestinal infectious diseases is foodborne. If the severity of foodborne disease was the same as that of intestinal infections from other sources, then foodborne disease annually would cause 83,000 hospitalizations, 2.6 million illnesses for which only a physician was consulted, 15 million cases involving no physician consultation but restricted activity for more than a day, and 15 million cases involving restricted activity for less than a full day.

The National Hospital Discharge Survey lists diagnoses for patients discharged from nonfederal, short-stay hospitals. Infectious and parasitic diseases are listed by the *International Classification of Diseases* (9th revision) (ICD-9) codes, which are specific to pathogens. For example, there are 15,408 cases for *Salmonella* (Code 003) (Table 5.3). Most cases of foodborne disease, however, are listed under the general codes of 008, 009, and 558.9 rather than under the causative microorganism.[7] Smith and Blaser (1985) found that in Colorado all diarrhea associated deaths are coded as noninfective diarrhea (Code 558) unless the word *infective* is mentioned on the death certificate. Further analysis of these data is required before definitive statements about hospitalizations for foodborne disease can be made.

Expert Opinion

Food scientists and epidemiologists, recognizing that reported data are just the tip of the iceberg, have made several attempts to determine the extent of foodborne disease incidence. Hauschild and Bryan (1980) estimated incidence of foodborne disease on the basis of about 50 thoroughly investigated foodborne outbreaks published in the scientific literature. The

[6]Studies include the Cleveland study, the Tecumseh study, the National Medical Care Utilization and Expenditure Survey, the National Health Interview Survey, and the National Hospital Discharge Survey (Garthright et al., 1988).

[7]Hospitalizations in the miscellaneous categories likely associated with food (008, 009, and 558.9) total 701,503 cases annually (Table 5.3). There may be two methods for estimating which percentage of these hospitalized cases is attributable to foodborne pathogens. Archer and Kvenberg (1985) analyze the National Ambulatory Medical Care Survey for 1977–1978 and suggest that 30 to 35% of physician visits is for intestinal infections with a foodborne cause. If this also were a good approximation for patients hospitalized in these three miscellaneous categories, then 210,000 to 245,510 hospitalizations/yr should be added to the list of hospitalizations with a foodborne cause. An alternative is to use Bennett et al.'s (1987) estimate that 95% of miscellaneous enteric disease is foodborne in origin for the high end of the range. Using this 30 to 95% range for miscellaneous foodborne hospitalizations yields an estimated range of 210,000 to 666,380 hospitalizations with a foodborne cause annually. To this can be added the 51,000 hospitalizations in Table 5.3 that are attributable to specific pathogens known to be associated with food. Resulting is an estimated 260,000 to 710,000 hospitalizations annually that may be due to foodborne pathogens.

Table 5.3. Patients discharged from hospitals, by category of disease likely to have been foodborne[a] by days of care, average length of stay, and average annual hospital costs, United States, 1987 through 1990 (adapted from Steahr and Roberts, 1993)

Diagnostic category and ICD–9–CM code	Yearly average	Average length of stay in hospital (days)	Average[b] annual hospital costs ($1,000)
Cholera 001	84	6.2	358
Typhoid 002	1,195	7.3	5,993
Salmonella 003	15,408	7.5	79,390
Shigellosis 004	5,344	4.6	16,888
Other food poisoning 005	5,958	3.3	13,507
Amebiasis 006	1,726	8.3	9,842
Other protozoal intestinal disease 007	6,125	8.1	34,084
Intestinal infections due to other organisms 008	139,382	7.5	718,166
Ill-defined intestinal infection 009	31,432	6.6	142,519
Listeriosis 027	1,089	13.9	10,399
Viral hepatitis A 070	12,404	8.9	75,842
Cysticercosis 123.1	1,133	8.0	6,227
Trichinosis 124	131	6.3	567
Unspecified gastroenteritis and colitis 558.9	530,689	5.4	1,968,750
Noxious substance eaten as food 988.9	698	3.2	1,534
All conditions above	752,798	6.0	3,084,066

[a]Includes patients with mention of disease on lines 1–7 of the hospital discharge certificate.
[b]Based on 1990 national average cost per day of $687 (U.S. Department of Commerce, 1992).

extrapolations for the United States ranged from 1.4 to 3.4 million cases per year.

Chalker and Blaser (1988) searched the literature and evaluated the likelihood of a salmonellosis case's being reported at each stage of the surveillance process (Table 5.4). Infections can go unreported because the infected person does not become ill, a sick person chooses not to see a physician, the physician does not obtain a specimen, the laboratory does not identify the microorganism from the specimen, the laboratory fails to report its test results to the health department, or the health department fails to report the laboratory test results to the CDC. Chalker and Blaser (1988) estimated the median reporting ratio for each step and obtained the total reporting ratio by successive multiplication of the ratio from each surveillance step. The total reporting ratio of 39 means that for each case of salmonellosis reported under the CDC's surveillance system, 39 human cases of salmonellosis are missed. Chalker and Blaser's estimates also contain the range of estimates reported in the literature for the number of illnesses not reported for each one that is. The range of ratios appearing in the literature also is shown. The actual underreporting ratio lies somewhere between 3.8:1 and 7,326:1.

Similarly, the basic technique to compensate for

Table 5.4. Summary of sequential artifacts in *Salmonella* surveillance (adapted from Chalker and Blaser, 1988)

Surveillance step	Estimated cases divided by reported cases	Range of estimates in the literature
Patient infected	1.0	
Patient ill	2.2	1.3 – 17.0
Patient consults a doctor	2.2	1.3 – 12.0
Doctor obtains a specimen	2.4	1.2 – 4.3
Laboratory identifies the organism	1.4	1.2 – 2.9
Laboratory reports to health department	2.0	1.3 – 2.4
Health department reports to Centers for Disease Control and Prevention	1.2	1.2[a]
Multiplier	39.0	3.8 – 7,326

[a]Only one study in the literature.

Note: Estimates of the degree of underreporting differed greatly for the first two steps—whether the infected person actually becomes ill and whether the ill person actually consults a physician. The variability in the reporting at each stage may be partly a function of the severity of illness due to variability in the number of *Salmonella* organisms ingested, the virulence of *Salmonella* serotype (Madden et al., 1986b), or host resistance/susceptibility as discussed in Chapter 3. *Salmonella* surveillance reporting ratio = 39.0; range = 3.8 to 7,326. The total multiplier of 39.0 is obtained by successive multipication of ratios from each surveillance step.

underreporting is to apply a multiplication factor to existing data. The recent publications of Bennett et al. (1987) and Todd (1989a, 1989b) estimated most known foodborne disease cases and are selected for discussion here. These publications contain estimates that are not at the high or low ends of the ranges and generally are considered by CAST task force members to be estimates based on defensible assumptions. Researchers at the CDC estimated morbidity and mortality for all infectious and parasitic diseases (Bennett et al., 1987), of which 17 were identified as foodborne diseases in whole or in part (Table 5.5). They used CDC surveillance and outbreak data, published reports, and expert opinion to estimate over-

Table 5.5. Best estimates of the annual cases and deaths for specific foodborne diseases in the United States

Foodborne disease or agent	Cases (No.)		Deaths (No.)	
	Bennett[a]	Todd[b]	Bennett[a]	Todd[b]
Bacterial				
Bacillius cereus	5,000	84,000	0	0
Botulism, including infant	180	270	7.2	3.9
Brucellosis	20	1,000	0.1	0.1
Campylobacteriosis	2,100,000	170,000	2,100[c]	1
Cholera	25	13,000	0.3	1.7
Clostridium perfringens	10,000	652,000	10	7.6
Escherichia coli O157:H7	ND[d]	25,000	ND	5.6
Escherichia coli (enteric)	50,000	44,000	100	0.6
Listeriosis	ND	25,000	ND	67.9
Miscellaneous enteric bacteria	190,000	107,000	1,900	11
Salmonellosis, nontyphi	1,920,000[e]	2,960,000	1,920	31.9
Shigella spp.	90,000	163,000	180	2.6
Staphylococcus aureus, excl. toxic shock syndrome (TSS)	1,513,000	1,155,000	1,210	5.9
Streptococcus Group A	500,000	52,000	150	0.2
Typhoid	480	240	28.8	0.1
Vibrio, infectious, excl. cholera	9,000	29,360	360	30
Yersiniosis, excl. plague	3,250	20,000	1.6	0.1
Total bacteria	6,380,955	5,500,870	7,968	170.2
Viral				
Hepatitis A	4,800	35,000	14	1.6
Norwalk-like agent/other 27 nm particles	ND	181,000	ND	0
Total viruses	?	216,000	?	1.6
Parasites				
Trichinosis[f]	100,000[f]	40,000	1,000[f]	3.8
Other parasites	ND	1,446,500[g]	ND	310.0
Seafood toxins	ND	58,260	ND	2.4
Plant poisons	ND	7,000	ND	5.9
Chemicals	ND	96,000	ND	5.4
Unknown agents	ND	5,217,000	ND	23.4
Total	6,485,755	12,581,630	8,982	522.7

[a]Bennett et al. (1987) omit food as the vehicle for some illnesses with partial foodborne etiology: listeriosis, toxoplasmosis, cysticercosis, *Escherichia coli* O157:H7 infection, Norwalk virus infections, rotavirus, and giardiasis.

[b]Todd's classification (1989b) differs from Bennett et al.'s (1987) in minor ways which include/exclude other species in the genus or associated disease syndromes. Todd's differing categories are *Streptococcus* spp. including Group A, *Vibrio cholerae/parahaemolyticus*, *Vibrio vulnificus*, and *Yersinia enterocolitica*.

[c]The latest Centers for Disease Control and Prevention estimates are 120–360 deaths from *Campylobacter* (Tauxe, 1992).

[d]ND = not done.

[e]Although some of the CAST task force contributors feel strongly that this estimate is too high, we do not have a verifiable lower estimate to offer.

[f]For trichinosis the cases and deaths originally reported are now considered excessive by both CDC parasitologists and some CAST task force members, but we were unable to agree on other estimates.

[g]Primarily *Toxoplasma gondii*.

all incidence and case-fatality ratio for each pathogen. The proportion spread by food was estimated for illnesses caused by each pathogen, and that estimate was used to allot cases and deaths to foodborne vehicles. The incidence of symptomatic illness from foodborne microorganisms was estimated at 6.5 million cases annually in the United States, with about 9,000 deaths.

Todd (1989a, 1989b) compared the estimates of Bennett et al. (1987) with estimates for the United States that were based on Canadian surveillance (this approach assumes that the underlying foodborne disease incidence is the same in both countries but that the different reporting systems cause different estimates). Four methods of extrapolating from outbreak data were used, each applying the same multiplication factor for all pathogens (with the exception of botulism and PSP). The methods included the following: (1) the CDC outbreak data multiplied by 350; (2) the Bennett et al. (1987) estimate used directly; (3) the CDC outbreak data multiplied by the estimated rate of salmonelloses underreporting, or 1,733; and (4) the Canadian estimates extrapolated to the U.S. based on population differences. The median of the estimates from these four methods was calculated and used. Todd (1989a, 1989b) used the same standard multiplication factor for all diseases, whereas Bennett et al. (1987) used a different multiplication factor for each pathogen. The greatest difference between the two sets of data is the number of deaths (Table 5.5).

Risk Models

As discussed in Chapter 3, risk assessment models may be used to evaluate potential health impacts of foods contaminated with pathogens. In addition to using the correct probability model, pathogen level must be determined accurately. Application of modeling to foodborne disease is in its infancy and is hindered for the following reasons.

1. Most methods recover only a fraction of the microorganisms present in foods; exposure, therefore, would be underestimated accordingly.
2. Surveys determining past contamination may not be useful in predicting future contamination.
3. Pathogen levels in meals served in homes and restaurants are not as well known as in commercial food and generally are rough estimates.
4. Risk models used to estimate the occurrence of foodborne disease generally are very uncertain although in the future such techniques may have sufficient precision to provide valuable estimates.
5. Complexity of cooking practices complicates risk modeling.
6. The impact of nonpathogenic bacteria, including spoilage organisms, in food or pathogens is unclear and may vary with the type of food and storage conditions.

If new studies sample foods for microbiological characteristics at the point of consumption and if we gain understanding of what an infective dose is, the modeling will become easier. Some studies have sampled raw and processed foods sold in supermarkets and other stores. Storage and preparation practices may increase or decrease the pathogen load on foods. Data on per capita consumption (including consumption patterns by age and by sex) of various foods exist and eventually could be used to estimate exposure to the risk of foodborne disease by specific pathogens in specific foods.

Limitations of Data Sources

None of the databases is designed to answer the questions (1) how many cases of foodborne disease are there or (2) what is the distribution of severity associated with each disease (Table 5.6). The limitations of current databases for foodborne disease estimation include the following:

1. The CDC outbreak data, which are designed to identify large foodborne disease problems threatening public health, require that two or more people have confirmed cases investigated by local or state authorities, a requirement that eliminates reporting of sporadic cases.
2. The CDC surveillance data usually are passive. The CDC sentinel surveys are limited to a few studies. Even for salmonellosis cases, survey sample size is small.
3. Expert opinion to arrive at "best estimates" of the extent of foodborne disease is based on extrapolations from outbreak and surveillance data.
4. Although medical case report data may identify new diseases and signal the kinds of disease outcomes caused by various pathogens, the data cannot be used to make reliable population estimates.
5. Medical data based on illnesses, hospitalizations, and deaths are incomplete. The Intestinal Infectious Disease Data do not identify causative pathogens that can be linked to foodborne sources. The National Hospital Discharge Survey lists most foodborne diseases under the miscellaneous

Table 5.6. Advantages of data sets for acute foodborne illnesses

Data set	Advantage	Cost
Outbreak data	Identify common-source outbreaks that typically are large or serious enough to justify an investigation and identify some foodborne cases	Medium
Laboratory surveillance	Identifies foodborne pathogens causing moderate to high to severe symptoms and is useful for quantitative risk assessment	High
Review of medical cases in the literature	May discover new diseases, pathologies, and severities, but is quite general	Low
Monitoring data from hospitals and public surveys	Identifies illnesses and deaths but often not specific foodborne pathogens	Medium
Sentinel county data and special epidemiology surveys	Identify case numbers, severity distributions, deaths, and may identify food vehicles. Useful for quantitative risk assessment	High

ICD-9 foodborne disease codes rather than under the specific codes for foodborne pathogens.

6. Modeling is a new approach that has been applied to specific examples and has not yet been used to generate comprehensive estimates of foodborne disease cases and deaths.

Data on Chronic Foodborne Illnesses

Data on long-term complications are not collected systematically.[8] Complications of foodborne illness may include arthritis, kidney damage, blood poisoning, heart disease, pancreatic infection, pneumonia, and neurological damage (Table 2.2). The range of possible effects is broad for most microorganisms. Archer and Kvenberg (1985) estimate that chronic illnesses are likely to occur in 2 to 3% of cases of foodborne infection. But identifying the specific chronic illness that a foodborne infection likely will cause is difficult. The long-term consequences of the chronic illness may be more serious than the acute illness (Archer and Young, 1988) (Table 5.7). Because symptoms may be neither unique nor linked temporally to a foodborne illness incident, chronic illnesses are especially difficult to relate to a specific pathogen or food vehicle.

Four examples of chronic illnesses that have been linked to foodborne disease are provided below to illustrate the magnitude of chronic illnesses and the potential to apply risk assessment procedures to understand these complications.

[8]Chronic complications sometimes are a function of infection, not illness, and can occur even if the immune system successfully fights off the illness. In such cases, activation of the immune system facilitates the chronic condition.

Chronic Sequelae of Toxoplasmosis

Congenital impairments associated with a maternal toxoplasmosis infection passed on to the fetus, range from mental retardation to blindness to hearing loss (Table 5.7). Roberts and Frenkel's (1990) review of the literature found most of the impairments were not immediately detectable. Table 5.7 shows the percentage detected in the first year, second year, and from the third through seventeenth years. What is striking is the high percentage of impairments. Only 20% of the children are without impairment after

Table 5.7. Impairments caused by congenital toxoplasmosis in prospective studies (adapted by Roberts and Frenkel, 1990)

	Couvreur et al. (1984)		Wilson et	
Impairment	1st yr (%)	Addl. in 2nd yr (%)	al. (1980) 3 to 17 yr (%)	Total affected (%)
Deaths	2	0	0	2
Severe illness	11	0	0	11
Severe retardation	11	+2	+20	33
Moderate retardation	5	+3	+9	17
Slight retardation	5	+6	+12	23
Blindness (bilateral)	6	0	+2	8
Moderate visual impairment	16	+17	+20	53
Strabismus[a]	5	+2	+13	20
Deafness[b]	2	0	0	2
Hearing loss (moderate unilateral)	0	+0	+10	10
Normal	55	36	20[c]	—

[a]Cross-eyed vision.
[b]Deafness varied widely, from 0 to 13%.
[c]After 20 yr.

reaching 20 years of age. While moderate visual impairment affects over half the cases, severe mental retardation sufficient to keep a child from working occurs in 33%. Moderate retardation, which is associated with reduced income and frequent unemployment, affects 17%. The majority of those with mild retardation are able to work at a wage only slightly below average.

The epidemiological information on the incidence of congenital toxoplasmosis is uncertain. Roberts and Frenkel (1990) suggested that cases range from 407 to 9,500 annually (1990). Roberts and Murrell use a "best estimate" of 4,179 cases annually (1993). The percentage attributable to food also is uncertain (Smith, 1993b). By looking at the age of exposed persons, Frenkel and Ruiz (1981) concluded that consumption of, and/or contact with, contaminated meat is a more important cause of toxoplasmosis in the United States than is contact with cats.

Another chronic syndrome associated with *Toxoplasma gondii* is toxoplasmic encephalitis, which can occur if an individual's immune system is impaired. AIDS and the side effects of certain cancer treatments weaken an individual's immune system, and old infections in muscles can be reactivated and cause severe complications or death. "Toxoplasmic encephalitis, marked by dementia and seizures, has become the most commonly recognized cause of central nervous system opportunistic infection in AIDS patients" (Schantz and McCauley, 1991). Steahr found 1,360 hospitalizations annually for toxoplasmic encephalitis (ICD-9 code 130.0) recorded in the National Hospital Discharge Survey from 1987 to 1990 (Roberts and Murrell, 1993).

Arthritis as a Sequela from Foodborne Pathogens

Diarrheic infections due to foodborne pathogens such as *Campylobacter jejuni*, *Salmonella typhimurium*, *S. enteritidis*, *Shigella dysenteriae*, *S. flexneri*, *S. sonnei*, or *Yersinia enterocolitica* may act as triggers of one of the reactive arthritides in susceptible individuals. There is strong familial association, i.e., individuals with the HLA-B27 antigen encoded by the major histocompatibility complex are more susceptible to arthritis induced by foodborne pathogens. Approximately 2% of a population exposed to a triggering infection will succumb; however, approximately 20% of exposed HLA-B27$^+$ individuals will develop arthritis. If there are 5 to 10 million cases annually of foodborne disease from these pathogens, there will be 100,000 to 200,000 cases of reactive arthritides annually (Edmonds, 1984; Smith et al., 1993).

The reactive arthritides are sterile, i.e., the triggering microorganisms cannot be isolated from the affected joints. The sterile reactive arthritides include reactive arthritis, Reiter's syndrome, and ankylosing spondylitis and are characterized by disease of the sacroiliac joint, peripheral inflammatory arthritis, and *absence* of rheumatoid factor. Other pathological effects may develop in the entheses (sites of ligamentous insertion into bone), eye, aortic valve, lung parenchyma, and/or genitals (Edmonds, 1984; Smith et al., 1993).

While only a fraction of the population is affected by arthritis after a case of food poisoning, the afflicted individuals undergo economic hardships. The protracted nature of the illness may prevent full-time productive employment and may involve medical expenses such as medicine, visits to physicians, and hospital stays. Thus, illness from foodborne pathogens is not always a simple one- or two-day inconvenience.

Hemolytic Uremic Syndrome as a Result of *Escherichia coli* O157:H7 Infection

Hemolytic uremic syndrome (HUS) has been known to be associated with food since 1982 and became well known as a result of enteric infections from the 1993 hamburger outbreaks in Washington, California, Nevada, and Idaho (U.S. Department of Health and Human Services, 1994). Various studies have estimated the incidence of *E. coli* O157:H7 disease to be 3 to 8/100,000 population annually, or 7,668 to 20,448 U.S. cases annually (Griffin and Tauxe, 1991; Marks and Roberts, 1993). Most of the cases are young children, although the elderly are the second most likely age group to be affected. Twenty percent of persons hospitalized for *E. coli* O157:H7 are estimated to develop HUS, a severe disease characterized by kidney failure and perhaps neurological impairment. Some individuals with HUS recover fully, some die, and a few develop chronic kidney failure—requiring lifelong dialysis or a kidney transplant (Figure 5.2).

Patients diagnosed with chronic kidney failure (approximately 24 to 63 cases annually) continue hemodialysis at the hospital on an outpatient basis, are able to perform peritoneal dialysis outside the hospital, or receive a transplant. Statistics for HUS pediatric patients show that by the end of the first year of treatment, 24% were undergoing hemodialysis in an office, clinic, or hospital; 29% were undergoing peritoneal dialysis; and 47% received a kidney

transplant. Over an average lifespan of 77 years, 17 to 42 chronic HUS patients are estimated to die from complications of either kidney dialysis or transplants. Many of these deaths occur before the age of 16.

Guillain-Barré Syndrome Preceded by *Campylobacter* Infections[9]

Campylobacter is the most common precipitating factor for Guillain-Barré syndrome (GBS), the leading cause of acute neuromuscular paralysis in the United States now that poliomyelitis has been virtually eliminated by vaccination programs (Mishu et al., 1993; Parry, 1993). Kennedy et al. (1978) estimate that the annual incidence of GBS is 1.7 cases in 100,000 people, or 4,250 new GBS cases in the United States annually. The GBS is considered to be an autoimmune disease with several antecedent triggering factors. Fifty to 75% of all GBS cases are preceded 1 to 3 weeks by an acute infectious illness of the gastrointestinal or respiratory tract (Mishu and Blaser, 1993). Although respiratory symptoms are reported most frequently, gastrointestinal symptoms precede GBS in 10 to 30% of cases. Mishu and Blaser (1993) estimate that 10 to 30% of all GBS cases are precipitated by *C. jejuni* infections, or *C. jejuni* accounts for 425 to 1,275 new GBS cases annually in the United States.

The GBS, as with other autoimmune diseases, can strike otherwise healthy individuals in their youth and early adulthood. Several studies found bimodal age distributions in GBS patients (Halls et al., 1988; Moore and James, 1981; Storey et al., 1989). In general, these studies showed an initial peak of GBS incidence for people in their twenties, a lower incidence for people in their thirties and forties, and the largest peak for people older than fifty. A similar age distribution was found for *Campylobacter jejuni* infections (Nolan and Harris, 1984).

Ropper et al. (1991) state that GBS "is usually a monophasic illness, with a rapid initial onset, progressive weakness over 1 to 4 weeks, and recovery over subsequent months." Although most GBS patients recover after several weeks or months, others are bedridden permanently or have fatal complications. Some patients have relapses. Hughes (1990) states that the prognosis of GBS varies and "up to 13% die and a further 20% are left significantly disabled" and unable to work after a year. Parry (1993) found that 85% of GBS patients he studied achieved a "complete functional recovery." Ropper et al. (1991) found that 75% of GBS patients recovered enough to return to normal life in 6 to 12 months and in one study, less than 15% had "absolutely no residual symptoms."

All documented GBS patients are hospitalized. Steahr (pers. com., 1994) analyzed hospital discharge data and found GBS (ICD-9 code 357.0) as the primary cause of 3,000 to 9,000 hospitalizations annually in 1987 to 1990. A review of nine articles on GBS revealed that 6 to 45% of all GBS patients were put

[9]This discussion is based on preliminary work by Jean Buzby, University of Kentucky and the USDA's Economic Research Service, and by Ban Mishu and Martin Blaser, Vanderbilt University, who are collaborating on research to estimate the incidence, severity, and costs of GBS associated with *C. jejuni*. Technically, *Campylobacter* enteritis is caused by two similar species: *C. jejuni* and *C. coli*. However, *C. jejuni* is the more prevalent species and often is used to discuss both species (Skirrow and Blaser, 1992). Guillain-Barré syndrome was once called acute postinfectious polyneuritis.

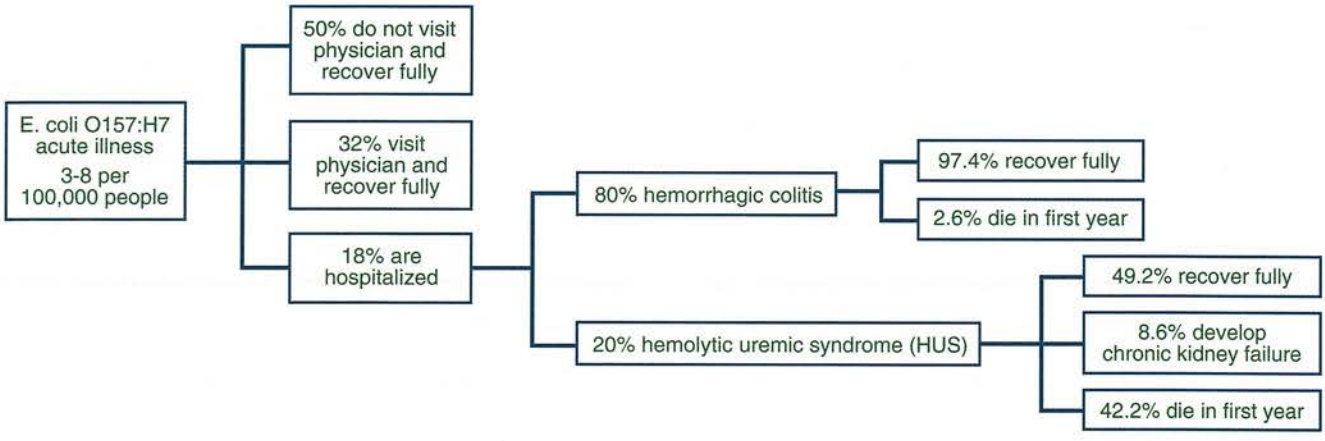

Figure 5.2. Estimated cases and severity outcomes for *Escherichia coli* O157:H7 infections (Marks and Roberts, 1993).

on ventilators to assist their breathing during some portion of their hospital stay. Sunderrajan and Davenport (1985) found that the mean hospital stay was 98.5 days for ventilated patients and 19.1 days for nonventilated patients.

Up to 65% of GBS patients report neurological pain (Beghi et al., 1985). One patient's pain persisted for more than one year (Andersson and Sidén, 1982). As with other illnesses involving lengthy hospitalizations, pain, and paralysis, GBS patients can face difficult psychological problems. Patients may worry about when the pain will cease, the extent that they may have a permanent disability or lingering minor deficits, and if they face a premature and impending death. Also, given the widespread occurrence of underinsured people and the high cost of ventilator treatment in a hospital, financial concerns may add to the mental burden of GBS patients and their families.

Discussion and Conclusions

All CAST task force members agreed that the outbreak cases reported to the CDC constitute a small fraction of the actual numbers. Although the literature provides estimated ranges of 1.4 million to 81 million cases annually (Archer and Kvenberg, 1985; Bennett et al., 1987; Hauschild and Bryan, 1980; Garthright et al., 1988; Todd, 1989b), realistically the range is more likely to be 6.5 million to 33 million cases annually. There are several factors to consider during evaluation of whether a foodborne disease likely will be identified:

1. The more serious the disease, the more likely it is to come to the attention of the medical community and the more likely it is to be reported.
2. The more distinctive the disease symptoms, the more clearly identifiable the causative microorganism.
3. The more quickly the disease follows the ingestion of the contaminated food (see incubation periods, Table 2.1), the more likely the foodborne association can be made.
4. The availability of rapid, inexpensive tests increases the likelihood of identification and reporting (viral causes of foodborne disease are exceptionally underreported).
5. "Name recognition" affects testing, e.g., physicians know that *Salmonella* causes food poisoning, which increases the likelihood that the stool sample will be tested for this bacterium.
6. When a great number of people become ill at the same time, the chances of a food being identified as the vehicle increase.

The importance of these factors and the degree of underreporting differ considerably by disease. "At the current level of disease surveillance (in the United States), it may take thousands of cases for an outbreak causing diarrheal illness randomly in a large urban area to be detected by public health authorities." (Berkelman et al., 1994)

In the future, we may be able to describe more fully the likely severity of disease caused by various pathogens and to calculate a probability distribution for disease severity by pathogen. For example, *Salmonella* has the full range of severity outcomes with much greater numbers of mild cases than deaths, *Listeria* may have a bimodal distribution with either mild or severe cases, and *Bacillus cereus* may cause only mild to moderate cases.

Estimates of deaths differ considerably, e.g., from hundreds to thousands. The CDC's estimates of 1,000 to 2,000 salmonellosis deaths (Table 5.2) were unacceptable to some CAST task force members because of the small sample size for the CDC's salmonellosis sentinel county survey. The National Research Council's (NRC) Institute of Medicine (1989) reported that 100 salmonellosis deaths are listed annually in the National Death Index (NDI) published by the National Center for Health Statistics (U.S. Department of Health and Human Services, 1984). For an additional 100 deaths annually, salmonellosis is listed as a contributing factor (U.S. Department of Health and Human Services, 1984). "The NDI data may underestimate the number of deaths from salmonellosis for several reasons: (1) a death certificate may be filled out by a physician or other authorized person who is not familiar with the illness of the deceased and may not recognize the contribution of the infection to 'cardiac arrest' or some similar noninfectious process; (2) a *Salmonella* infection may be recognized and reported as septicemia, meningitis, or other infection without identification of the causative microorganism; or (3) failure to take a bacterial culture from a patient with salmonellosis as a complication of a terminal illness might lead to failure to identify the organism."

The NDI is a compilation of death certificate information from the states' vital statistics offices. The death certificate is not intended as an epidemiological tool; hence, the epidemiological information on the certificate can be both limited and inaccurate as to actual cause of death (Hopkins et al., 1989; Israel et al., 1986; Rosenberg, 1989).

While recognizing that there is great uncertainty

associated with estimates of annual foodborne deaths, the majority of CAST task force members was willing to accept the Bennett et al. (1987) "best estimate" of around 9,000 deaths annually from foodborne microbes (Table 5.5). Some thought that the Bennett et al. (1987) estimates for deaths were excessively high and were more comfortable with Todd's estimate of 200 to 500 foodborne deaths annually (Table 5.5).

Another issue is the underlying health of individuals dying from foodborne pathogens. In the western states in early 1993, the *Escherichia coli* O157:H7 associated with undercooked hamburger infected healthy children primarily, a few of whom died (Centers for Disease Control and Prevention, 1993b). Additional outbreaks and deaths of children from *E. coli* O157:H7 were reported in Texas in November 1993 (Steele, pers. com., 1993). Other pathogens, e.g., *Listeria monocytogenes*, mainly cause severe illness and death in persons with immature (fetal) or compromised immune systems (adults with cancer, diabetes, renal disease, heart disease, or AIDS) (Schwartz et al., 1988). For other pathogens, the severity of illness may depend largely on number of microorganisms ingested as well as on individual susceptibility factors (Table 3.2). Until better data are available, the likelihood of a healthy versus an infirm individual's dying from exposure to foodborne pathogens cannot be determined.

As data from new epidemiological studies and increased microbial testing become available, estimates of foodborne disease number and case severity will continue to improve for both acute and chronic illnesses. New foodborne pathogens also will be discovered for human illnesses previously thought unassociated with food. And as the *Escherichia coli* O157:H7 case indicates, mutations and evolving econiches will create new concerns.

There is much uncertainty in the estimates of case number, foodborne association, and disease severity. Deaths, because of their small number and great importance, were flagged in data collection efforts. Given current information, the majority of the CAST task force believes that foodborne disease may range from 6.5 million to 33 million cases annually and that foodborne deaths may be as high as 9,000 annually. Five hundred deaths annually due to foodborne pathogens is a conservative low estimate.

6 Risk Characterization: Economic Costs of Foodborne Diseases

The final step in risk assessment is characterizing the economic and social consequences of estimated risks. The wide range in estimated acute foodborne diseases (6.5 million to 33 million cases and as many as 9,000 deaths annually) considered realistic by the CAST task force and the inability to quantify chronic disease systematically causes cost estimates to vary widely.

Several methods exist for estimating the costs of foodborne disease to society and the value society places on reducing the risk of foodborne disease: (1) the cost-of-illness (COI) method estimating medical costs and productivity losses, (2) surveys of the willingness to pay for safer food, (3) experimental auctions for purchase of food with different levels of safety, and (4) indices of health status during episodes of foodborne illness. The limited literature on the economic costs of foodborne disease is reviewed.

Introduction

The likelihood of foodborne disease is affected by the actions of three groups—consumers, industry, and the government. These three groups affect the consumption of foods as well as the probability that a certain food contains pathogens (Figure 6.1). Foodborne disease costs can be valued from the perspective of each of these groups—that of the consumer at risk of foodborne illness from eating food; that of the industry at risk of losing business if a foodborne disease outbreak is associated with their food (and increased costs to prevent the outbreak by changing production practices); and that of the public health sector, which may use resources in investigating foodborne disease outbreaks as well as in preventing them. Social costs for the whole society also can be estimated. In any case, double counting must be avoided—a particular concern for industry costs, for in a local area, one restaurant's lost customers become another's new ones (liability costs to a firm may be adequate compensation for the pain and suffering and other costs of illness for an affected consumer).

Economists use two main methods for valuing food safety. The older is the COI method, which is based on estimating the resources that society would save by avoiding foodborne illness. The newer willingness-to-pay (WTP) method has been used to estimate values for clean air and water as well as for safe food (Mitchell and Carson, 1989). Surveys, auctions, and indices of health status have all been used to gain

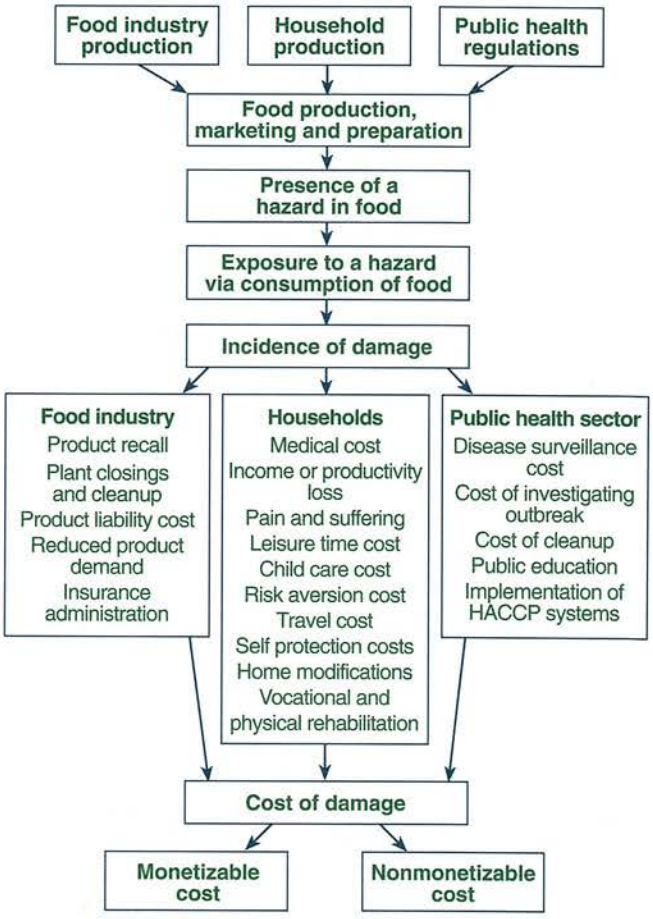

Figure 6.1. Foodborne disease, exposure, and types of costs.

insight into the "willingness to pay" for safer food. These methods and their usefulness to food safety evaluation efforts are discussed.

The Cost-of-Illness Method

Some economists and policymakers prefer to use known cost data, e.g., COI data. Usually, the perspective of the consumer becoming ill with a foodborne disease is used, and the backbone of cost estimates is (1) medical costs to treat the illness and (2) productivity losses because the ill person was not at work. In the literature, medical costs may be called *direct costs*, and productivity losses, *indirect costs*.

Other costs, e.g., loss-of-leisure cost, borne by ill persons may be included in the estimation (Figure 6.1). And sometimes the costs may be estimated for the other two actors in the food-safety arena—the industry and the public health sector.

Costs are estimated on either an incidence basis for persons becoming ill in any one year or on a prevalence basis, e.g., what are the current disease burdens of all end-stage renal disease cases, some of which developed in previous years? Similarly, when comparing public health protection benefits with alternative intervention costs, it is important to identify whether control procedures are one-time costs or costs that can be expected to occur each year.

Industry, the government, and consumers also engage in behaviors to prevent foodborne disease. Some economic analyses include the costs of prevention activities as well. Harrington and Portney (1987) suggest that COI estimates are a lower bound and that a more complete picture would include estimates for psychic costs, e.g., pain-and-suffering, as well as disease prevention costs.

Most cases are acute illnesses from which recovery is rapid. In a small percentage of cases, acute foodborne illnesses may affect persons for several years or for a lifetime (see Table 2.2). Either because a chronic condition develops at a later date or because the disease has caused permanent physical or mental damage requiring ongoing medical attention or causing reduced lifetime earnings, costs may be incurred over the lifetime of an individual becoming ill with a foodborne disease. Cost estimates are converted into a present value (a value today for a lifetime's earnings or medical expenses), and economists generally agree that the discount rate to use ranges from 2 to 5% when consumers' willingness to exchange future consumption for present consumption is examined (see special *J. Environ. Econ. Manage.*, 1990 supplement).[10]

Landefeld and Seskin's (1982) formula for estimating the value of a statistical life lost, or unidentified person, is an extension of the COI method (Table 6.1). They sum lifetime productivities in the marketplace and in the home, discount the sum to arrive at a present value, and add a risk-aversion premium, α, that reflects the amount that individuals purchasing life insurance pay for the premium over the potential income loss due to death of a household member.[11] Landefeld and Seskin's formula values a person's life according to earning power, and earning power depends on age, gender, race, education, and other socioeconomic variables.

Cost-of-Illness Estimates in the Literature

Estimates of foodborne disease costs often omit estimates of death. For example, Garthright et al. (1988) omitted deaths in their analysis of intestinal infectious illnesses (Table 6.2). If foodborne sources cause one-third of cases, as Archer and Kvenberg (1985) suggest, estimated costs for foodborne disease (excluding deaths) are $7.7 billion annually (1985 dollars; updated to 1992 dollars, $9.4 billion/yr). Their study is based on actual reports of intestinal illness symptoms; however, how the researchers determined

[10]The Office of Management and Budget generally uses a higher estimate, especially when evaluating public works programs for which public is competing with private investment. Lower interest rates, if justified, can be used.

[11]Dorothy Rice, pioneer in codifying the human capital method of calculating COI, continues to omit the risk-aversion factor (Rice et al., 1989).

Table 6.1. Landefeld and Seskin's (1982) formula for estimating the value of a statistical life lost[a]

Landefeld and Seskin's value-per-statistical life = $\alpha \sum_{t=1}^{n} \frac{Y_t}{(1+r)^t}$

n = years of remaining lifetime
Y_t = after-tax income = $L_t + N_t$
where
L_t = labor income[a]
NL_t = nonlabor income

r = individual's opportunity cost of investing in risk-reducing activities
α = risk-aversion factor
t = one year

[a]May include the imputed value of nonmarket time spent on housekeeping activities.

Table 6.2. Cost estimates for medical expenses and value of lost productivity from intestinal infectious diseases[a], U.S. population, in 1985 dollars (Garthright et al., 1988)

Cases	U.S. cases in 1980 (No.)	Medical cost per case ($)	Lost productivity value per case ($)	Medical cost (million $)	Lost productivity value (million $)	Combined cost (million $)
Hospitalized with consultation by physician	250,000	$2,255	$783	$560	$200	$760
Nonhospitalized, with consultation by physician	7,900,000	87	261	690	2,060	2,750
No consultation by physician	90,800,000	0	215	0	19,500	19,500
Total (rounded)				$1.25 billion	$21.8 billion	$23 billion[a]

[a]One-third of these could be foodborne (Archer and Kvenberg, 1985).

what percentage of symptoms was related to food is unclear. A greater disadvantage is that people do not know which pathogens made them ill; hence, the number of cases or the severity of the disease cannot be associated with specific pathogens. Identification of specific pathogens is necessary to estimate the likely public health protection benefits of alternative control strategies for foodborne pathogens from the farm to the fork.

Estimates by others have indicated death as a very large if not the largest component of foodborne illness costs (Mauskopf et al., 1988; Roberts, 1989). Estimates of medical costs and productivity losses include the following: (1) salmonellosis deaths were the largest component of costs for the high-case estimate and a close second for the low (Roberts, 1989); (2) productivity losses caused by deaths dominated listeriosis costs (Roberts and Pinner, 1990) (Table 6.3); (3) deaths during acute illness dominated *Escherichia coli* O157:H7 costs (Marks and Roberts, 1993, Table 6.4); but (4) the chronic costs of mental retardation dominated costs of congenital toxoplasmosis (Roberts and Frenkel, 1990). Because Mauskopf and French (1991) value a statistical life at $5,667,000 for salmonellosis deaths, a value several times greater than Roberts', deaths dominate their cost estimates.

The USDA's Economic Research Service has estimated 1992 costs for several bacterial and parasitic pathogens (Table 6.5). Costs per case differ dramatically, in that disease severity is exceedingly diverse. Foodborne toxoplasmosis was the most costly disease, at $2.6 billion annually, followed by salmonellosis, campylobacteriosis, diseases caused by *Escherichia coli* O157:H7 (Figure 5.2), and listeriosis. These diseases are estimated to cost in total between $5 billion and $6 billion annually (Weiss et al., 1993; Ta-

Table 6.3. Estimated annual costs of listeriosis illnesses and deaths, 1987 (Roberts, 1989)

Syndrome	Cases (No.)	Medical costs (million $)	Productivity losses (million $)	Total costs (million $)	Average cost/case ($)
Maternal illness	252	1.8	0	2	7,100
Fetal/infant					
Patients who died	79	0.4	86.9[a]	87	1,100,000
Patients who survived	281	12.0	20.0[b]	32	71,000
Other adult					
Patients who died	431	7.5	113.4	121	281,000
Patients who survived	817	13.6	0.5	14	17,000
Total	1,860	35.3	220.8	256	135,000[c]

[a]The productivity loss includes 65 stillbirths or spontaneous abortions and 14 live births that resulted in death. The productivity loss for only the live births is $15.4 million.

[b]Reduction in earnings for those developing neurological problems.

[c]Rounded down to the nearest $5,000. If stillbirths and spontaneous abortions are excluded from the cost and case estimates, the average cost per illness is $100,000/case.

Table 6.4. Estimated annual incidences of *Escherichia coli* O157:H7 illness and costs (data from Marks and Roberts, 1993)[a]

Severity of illness	Share of reported cases (%)	Annual cases (No.)		Medical costs (million $)		Productivity losses (million $)		Total costs (million $)	
		Low	High	Low	High	Low	High	Low	High
No physician visit	50.00	3,834	10,224	0	0	0.6	1.7	0.6	1.7
Visited physician	32.00	2,454	6,543	0.4	2.0	0.8	2.2	1.2	4.2
Hospitalized	NA[b]	NA	NA	NA	NA	NA	NA	NA	NA
Hemorrhagic colitis	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acute illness deaths	0.38	29	78	0.3	0.8	34.2	91.9	34.5	92.7
Full recovery	14.02	1,075	2,867	11.4	30.5	1.3	3.5	12.7	34.0
Hemolytic uremic syndrome (HUS)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acute illness deaths	1.52	116	311	4.0	10.6	136.7	366.4	140.7	377.0
Full recovery	1.77	136	362	4.6	12.4	0.7	2.0	5.3	14.4
Chronic illness	0.31	24	63	8.3	21.3	13.0	35.1	21.3	56.4
Total	100.00	7,668	20,448	29.0	77.6	187.3	502.8	216.3	580.4

[a]Numbers may not total due to rounding.
[b]NA = not applicable, because these are case totals.

ble 6.5). Many of the foodborne diseases mentioned by Bennett et al. (1987), however, have no cost estimates (Table 5.5). Some CAST task force members believe that these estimated human illness costs are high because case and death estimates are "best estimates" of actual cases from Bennett et al. (1987) as well as from other sources.

Todd compiled cost information about 67 outbreaks of foodborne disease occurring in Canada and the United States and calculated average costs per pathogen (Todd, 1989a, 1989b). In a companion article, Todd (1989b) calculated estimates of average and total costs for foodborne disease in the United States (Table 6.6). He used the Landefeld and Seskin method for valuing loss of life in both. Todd estimated annual costs for foodborne disease in the United States at $5 billion to $8 billion.

Todd (1989a, 1989b) assumes fewer deaths from

Table 6.5. Medical costs and productivity losses estimated for foodborne pathogens, 1992 (Weiss et al., 1993)

Foodborne pathogen[a]	Cases (No.)	Deaths (No.)	Medical and productivity costs (million $)
Bacterium			
Salmonella	1,920,000	960–1,920	1,188-1,588
Campylobacter jejuni or *coli*	2,100,000	120–360	907–1,016
Escherichia coli O157:H7[b]	7,668–20,448	145–389	216–580
Listeria monocytogenes	1,526–1,581	378–433	209–233
Parasite			
Toxoplasma gondii	2,090	42	2,628[c]
Trichinella spiralis	131	0	0.8
Taenia saginata	894	0	0.2
Taenia solium	210	0	0.1[d]
Total			$5 billion to $6 billion/year

[a]Analysis assumes that 100% of human illnesses are foodborne for *Campylobacter*, *Escherichia coli* O157:H7, *Trichinella*, and the *Taenia* spp. and assumes that 96% of *Salmonella*, 85 % of *Listeria*, and 50% of *Toxoplasma* cases are foodborne.
[b]Marks and Roberts, 1993 is source for *E. coli* O157:H7 estimates.
[c]Productivity losses are high for survivors who develop mental retardation or blindness as a result of toxoplasmosis. These costs exclude premature death (50% of cases also may have a foodborne origin).
[d]Estimates do not include costs for cystericercosis, which may have an indirect foodborne transmission.

foodborne illness than does Roberts (1989). And costs differ from outbreak to outbreak, reflecting differences in media coverage, liability suits, and other factors that can be largely coincidental and unrelated to the outbreak, as well as disease severity and other directly related factors. Todd's (1989a, 1989b) estimates thus depend on which categories of costs are included—medical costs for ill persons, industry lawsuits, government investigations, etc., the combination of which makes comparisons difficult either across pathogens or for the same pathogen. The strength of Todd's estimates is that costs are based on real foodborne disease outbreaks. By relying on the best judgment of researchers in arriving at total foodborne cases, Todd (1989a, 1989b) encounters the same problems that Roberts (1989) does.

Willingness-to-Pay for "Safer" Food

One concern with the COI method is theoretical: there is no necessary correspondence between the COI and the value that a person would place on not having the illness. The WTP approach is preferred because it is more compatible with economic theory; demand theory is built on what people are willing to pay for a good or a service. Steady progress has been made using the WTP method to evaluate recreational benefits, job related risks, and environmental attributes (Fisher et al., 1989; Mitchell and Carson, 1989). Some studies use survey techniques to ask people what they would be willing to pay for certain contingencies (contingent valuation method); others use laboratory simulations to see what participants will bid in an auction; others examine markets to tease out hidden values by examining risky attributes of consumer products or the wage/risk tradeoff in labor markets (hedonic method).

Only a few estimates of WTP to avoid foodborne disease appear in the literature. The contingent valuation method, whereby subjects are asked to evaluate how much they would be willing to pay to avoid certain contingencies—has been used in a few studies. Unfortunately these studies have not been replicated—an important consideration inasmuch as survey questions must be easily understood and nonprejudicial to yield accurate and unbiased results. In a survey of Kansas consumers, Kramer and Penner (1986) found consumers willing to pay $.01 to $.03 per pound more for beef free of unwanted residues. Smallwood (1989) reported a nationwide survey in which over one-half of respondents were willing to pay about $.17 more per pound for "disease-free" chicken. (Nearly one of three respondents expressed a willingness to spend up to 20 additional minutes in preparation and cleanup to reduce the risk of foodborne illness).

Preliminary results of laboratory experimental markets in which persons were given a regular commercial sandwich and subsequently offered a "safer" sandwich, suggest that people are willing to pay relatively large premiums to avoid microbial pathogens. Reduction in the risks of foodborne disease to a one-in-100-million chance was worth $.55 and $.81 per sandwich for *Salmonella* and for *Trichinella spiralis*, respectively (Shin et al., 1992). (The risk information given participants, however, seemed to overstate the risk of becoming ill from eating the sandwich.)

Mauskopf and French (1991) use health status indexes to estimate costs for several foodborne diseases. The advantage of this technique is that the scope of the estimate is broader than medical costs and productivity losses and measures all sources of well-being associated with change in health status. People are surveyed to compare different levels of health status. Ratings are given for restrictions in mobility, social interaction, and physical activity, and for pain or other symptoms.

One concern with ranking health states is whether the results can be replicated. Sample sizes have been small, responses variable, and different questions used. Also, different procedures may have been used, e.g., how were people told to account for medical insurance or paid sick-leave before answering questions about wages/time lost from work?

A final concern is calculating losses caused by chronic illnesses with a foodborne source. Case estimates are rather vague although Kvenberg and Archer (1987) estimate that such effects occur in 2 to 3% of all infections. The range of estimates for annual cases of foodborne diseases is the 6.5 million to 33 million annually discussed earlier, or 130,000 to 990,000 new cases of chronic disease annually.[11] Thompson (1986) surveyed rheumatoid arthritis sufferers and asked what they would be willing to pay

[11]If these chronic diseases were to persist throughout the hosts' remaining lifetimes, 25 years is a reasonable estimate of the years of life remaining for each host (people who die from salmonellosis, die, on average, 25 years before the average person dies) (U.S. Department of Health and Human Services, 1984). Thus, an estimated 3 million to 25 million persons may suffer from chronic conditions caused by foodborne disease.

Table 6.6. Total cost of foodborne disease in the United States (adapted from Todd, 1989b)

Etiologic agent	Estimated foodborne disease cases[a]	Illnesses because of mishandling in food service establishments, homes, etc.			Illnesses because of mishandling in food processing establishments			Deaths			Total cost (million $)	Average cost per case ($)
		% of cases[b]	Cost/case ($)[c]	Total cost (million $)	% of cases[b]	Cost/case ($)[c]	Total cost (million $)	No.[a]	Value ($)	Total cost (million $)		
Bacteria												
Salmonella (not *S. typhi*)	2,960,000	95	887	2,494	5	10,037	1,486	31.9	358,000[d]	11	3,991	1,350
Staphylococcus aureus	1,155,000	93	460	494	7	12,610	1,020	5.9	358,000[e]	2	1,516	1,310
Listeria monocytogenes	25,000	0?	NA	0	100?	11,543	289	67.9	358,000[e]	24	313[i]	12,520
Campylobacter spp.	170,000	100	916	156	0	NA	0	1.0	358,000[e]	0	156	920
E. coli (not O157:H7)	44,000	75?	887[e]	29	25?	10,037[e]	110	0.6	358,000[e]	0	139	3,160
Clostridium perfringens	652,000	100	184	120	0	NA	0	7.6	358,000[e]	3	123	190
Yersinia enterocolitica	20,000	50?	887[e]	9	50?	10,037[e]	100	0.1	358,000[e]	0	109	5,450
Clostridium botulinum	270	99	18,071	5	1	30,061,710	81	3.9	358,000[e]	1	87	322,200
E. coli O157:H7	25,000	100	3,276	82	0	NA	0	5.6	358,000[e]	2	84	3,360
Shigella spp.	163,000	100	375	61	0	NA	0	2.6	795,000[d]	2	63	390
Vibrio vulnificus	29,000	100	887[e]	26	0	10,037[e]	0	30.0	358,000[e]	11	37	1,275
Bacillus cereus	84,000	96	411	33	4	1,000[e]	3	0.0	358,000[e]	0	36	430
Streptococcus spp.	52,000	90?	500	23	10?	1,000[e]	5	0.2	358,000[e]	0	28	540
Vibrio cholerae/ parahaemolyticus	13,000	100	887[e]	12	0	NA	0	1.7	358,000[e]	1	13	1,000
Brucella spp.	1,000	90?	5,000[e]	5	10?	20,000[e]	2	0.1	358,000[e]	0	7	7,000
Salmonella typhi	240	99	10,757	3	1	349,786	1	0.1	485,000[d]	0	4	16,670
Other enteric bacteria	107,000	75?	500	40	25?	1,000	27	11.0	358,000[e]	4	71	660
Total bacteria	5,500,510			3,592			3,124	170.2		61	6,777	1,240
Viral												
Hepatitis A	35,000	100?	5,000[e]	175	0	NA	0	1.6	609,000[d]	1	176	5,030
Norwalk agent	181,000	100?	887[e]	161	0	NA	0	0	NA	0	161	890
Total viruses	216,000			336			0	1.6		1	337	1,540
Parasites												
Toxoplasma gondii											445	310
(a)	1,435,437	100	50[e]	72	0	NA	0	1.0	485,000[d]	0		
(b)	2,063	100	110,844[f]	229	0	NA	0	309.0	485,000[d]	144		
Trichinella spiralis	40,000	86	2,485[g]	86	14	10,037[e]	56	3.8	485,000[d]	2	144	3,600
Giardia lamblia	7,000	100	5,128	36	0	NA	0	0.0	NA	0	36	5,140
Taenia spp.	1,000	100	111[g]	0	0	NA	0	0.0	485,000[d]	0	0	110
Fish parasites	1,000	100	111[e]	0	0	NA	0	0.0	NA	0	0	110
Total parasites	1,486,500			423			56	313.8		146	625	420

Table 6.6. (continued)

Etiologic agent	Estimated foodborne disease cases[a]	Illnesses because of mishandling in food service establishments, homes, etc.			Illnesses because of mishandling in food processing establishments			Deaths			Total cost (million $)	Average cost per case ($)
		% of cases[b]	Cost/case ($)[c]	Total cost (million $)	% of cases[b]	Cost/case ($)[c]	Total cost (million $)	No.[a]	Value ($)	Total cost (million $)		
Seafood toxins												
Ciguatera toxin	27,000	100	3,983	92	0	NA	0	2.1	358,000[e]	1	93	4,040
Scombroid poison	31,000	8	500[e]	1	92	1,000[e]	29	0.0	NA	0	30	970
Paralytic shellfish poisons	260	100	6,000[e]	2	0	NA	0	0.3	358,000[e]	0	2	6,400
Total seafood toxins	58,260			95			29	2.4		1	125	2,300
Poisons												
Plant poisons	7,000	48	82	0	52	500[e]	2	5.9	358,000[e]	2	4	570
Chemical poisons	96,000	80	100[e]	8	20	1,000[e]	19	5.4	358,000[e]	2	29	300
Total known	7,364,270			4,454			3,230	499.3		213	7,897	1,080
Total unknown	5,217,000	98	100[e]	511	2	100[e]	10	23.4	358,000[e]	8	529	100
Total	12,581,270			4,965			3,240	522.7		221	8,426	670
Total percentage of costs				58.9			38.5			2.6	100.0	1,140[h]

[a]Cases estimated from Table 1, deaths from Table 2 in Todd, 1989b.
[b]Percent of cases for foodservice establishments, etc., and food processing establishments from Canadian and U.S. outbreak data.
[c]Costs from Todd (1989a).
[d]Based on data from U.S. Department of Health and Human Services (1984) and Landefeld and Seskin (1982).
[e]No cost data available, best estimates given; *E. coli* (not O157:H7), *Yersinia, Vibrio*, spp., and Norwalk agent were assumed to have the same cost per case as *Salmonella; Brucella*, and hepatitis A were allotted higher figures because of the seriousness of these illnesses; fish parasites were assumed to be equivalent to *Taenia* ($111/case); other agents were given figures estimated to be appropriate to the significance of the disease; values of deaths equivalent to those for salmonellosis where cost data not available.
[f]See Table 2 footnote [f] in Todd, 1989b for two types of toxoplasmosis cases; costs of congenital cases from Wilson and Remington (1980).
[g]Costs from Roberts (1985).
[h]Median cost of average costs per case for each disease.
[i]The 25,000 listeriosis cases include those that range from mild to severe. If it is assumed, according to the most recent CDC estimates for listeriosis, that there are 1,700 serious sporadic infections with 450 deaths and 100 stillbirths (Gellin and Broome,1989) and the mild cases are ignored, the cost would be $216 million, assuming each death/stillborn is worth $358,000.

for an arthritis cure. The answer was an average of 22% of household income. Although rheumatoid arthritis is a more severe outcome than most chronic foodborne illnesses, such cost information makes an important addition to the acute illness costs reviewed here.

Discussion

The three researchers, with relatively comprehensive estimates of foodborne illness costs, used the COI method and estimated annual U.S. costs in the billions of dollars (Tables 6.2, 6.5, and 6.6). Although each study and method has its inadequacies, the fundamental need is to improve the underlying estimates of foodborne disease cases and deaths and therefore our understanding of the magnitude of foodborne illness in the United States.

In the future, researchers will develop the WTP method and will develop comprehensive estimates of the value of reducing foodborne disease risks. The few preliminary studies have shown WTP estimates to be much greater than COI estimates (Mauskopf and French, 1991; Shin et al., 1992; Smallwood, 1989).

7 Prevention of Foodborne Illness

The good safety record of the U.S. food supply has been accomplished by voluntary and regulated control activities primarily undertaken by or directed toward the food industry, surveillance activities, and educational activities. New opportunities exist or are being developed that will complement or replace historical efforts to enhance control from the source to the consumer by preventing the occurrence of pathogens in foods or by reducing their numbers or destroying them.

Introduction

Current and historical measures used to prevent and to control foodborne infections and intoxications can be classified as voluntary processing and handling controls practiced by the food industry plus *surveillance*, *educational*, or *regulatory* activities (Bryan, 1986; 1992a). Voluntary controls practiced by the food industry largely are responsible for the good safety record of the U.S. food supply. There is *surveillance* of (1) diseases; (2) food establishment workers; (3) foods; (4) facilities in which foods are processed, transported, stored, and prepared and equipment on which foods are processed and prepared; and (5) operations (practices, procedures, or processes) to which foods are exposed. *Educational* activities include both (1) training professional public health, regulatory, and food-industry quality-control personnel in matters related to prevention and control of foodborne diseases and (2) educating food-industry managers, supervisors, and workers, as well as the public, about hazards and risks associated with foodborne diseases and their prevention. Foodborne-disease *regulatory* activities include product inspection, process inspection, product recall, and legal action (including fines and criminal prosecution). Opportunities exist to apply current knowledge and modern approaches and technologies to enhance food safety today and in the future. The following provides details of historical and current methods, some successful and some unsuccessful, as well as modern options for enhancing food safety.

Voluntary Food Industry Controls

Voluntary controls practiced by the food industry to enhance food safety are varied and include adherence to good manufacturing practices (GMPs), voluntary implementation of the hazard analysis critical control point (HACCP) programs (described below), use of sanitation practices exceeding those required, use of microbiological specifications in decisions regarding purchases and processing, and use of educational and training programs for personnel, for example. The food industry supports food safety research to enhance the understanding of pathogenic microorganisms and the control of the organism and its toxic end products and supports the exchange of food safety information within the industry. In many instances, processing (time/temperature of pasteurization, sterilization, or final pH in a fermentation) requirements are more rigid than required to ensure pathogens will not be a concern in the processed, packaged food. In many cases, the approaches voluntarily used by individual companies later become industry standards and, in some instances, regulatory requirements because of their successes. For example, HACCP was an industry initiative voluntarily adopted by much of the industry and now is likely to be adopted soon as a regulatory approach.

Surveillance of Diseases

The primary purpose of surveillance is to provide a basis on which to take rational action to control continuing outbreaks and to prevent additional occurrences. Surveillance of diseases is an indispensable part of every successful disease control program, yet foodborne disease surveillance is either nonexistent or ineffective in many jurisdictions. Nearly one quarter of states have no surveillance staff assigned to monitor food associated pathogens (Berkelman et al., 1994). Useful surveillance programs seek notification of illness, identify and investigate outbreaks, inter-

pret investigative data, and disseminate findings (Bryan et al., 1987).

Investigations of outbreaks and sporadic cases of foodborne disease should consist of (1) taking steps to verify diagnoses (including collection of case histories and specimens); (2) making time, place, and person associations; and (3) reviewing operations of the establishment at which foods likely were mishandled. This last step includes interviewing managers and workers, collecting samples, tracing routes of contamination to their source—if possible, examining workers, and identifying operations contributing to the outbreak. This crucial phase of investigation must account for contamination of the implicated food; survival of pathogens or toxins during heat processes, if applicable; and multiplication of foodborne pathogenic bacteria to such an extent as either to create numbers or to produce toxins in quantities sufficient to cause illness.

Presently, once a food is implicated, its sale is stopped, products already sold are recalled, and safeguards are established and monitored. Application of the risk assessment approach would provide input of cost-benefit information into the decision of how to handle implicated foods in the marketplace. Salient features of the outbreak should be communicated to the agency responsible for disease surveillance at the national level, i.e., the CDC, and to other scientists. These information channels improve our knowledge and ability to reduce the occurrence of foodborne disease. Information about the factors contributing to an outbreak should be used either to select or to devise and implement both control and prevention measures in the implicated establishment and other locations (Bryan, 1988a, 1988b). Factors contributing to outbreaks associated with homes, food service establishments, and food processing plants are presented in Table 7.1.

In time, surveillance data become bases for determining predominant foodborne diseases in a community, for indicating principal vehicles, and for identifying primary factors contributing to the occurrence of outbreaks of foodborne disease.

With advances in epidemiology and rapid testing for microbial pathogens, and given sufficient funding, a risk assessment database, which would be a superior tracking and monitoring system, could be established for use by food safety and public health professionals and by regulators. The CDC now collects and disseminates some of these data in its foodborne disease outbreak reports. Expanding the scope of the CDC's efforts, linking it to data collected in other health surveys, and linking it more closely to food vehicles would improve the ability of the FDA and the FSIS to quantify foodborne disease risks and fashion regulatory programs to reduce human illnesses from foodborne sources (Table 7.2). Particular attention should be given to strengthening identification of microbial foodborne deaths, both because of the importance of achieving a consensus on the number of foodborne deaths and because of the high social costs associated with deaths (Roberts and Smallwood, 1991).

Human health databases could be searched for information about foodborne pathogens identified by ICD-9 codes. Sources include public and private hospital databases, death databases, and doctor visit databases (Gangarosa et al., 1992; Garthright et al., 1988; Glass et al., 1991; Lew et al., 1991). Special studies may be necessary to identify the pathogens for cases entered in the miscellaneous categories (Table 5.3). Analysis of these databases could clarify how many people become ill enough to seek medical attention. Emerging pathogens could be detected to provide to industries, consumers, and regulators feedback on the success of various forms of intervention, e.g., additional laboratory food testing, food handling and meat cooking instructions, HACCP programs, and industry education.

The CDC has proposed expanding its foodborne disease sentinel surveillance (Bryan et al., 1994) and including a geographically representative sample of urban and rural populations and public and private health care providers. Such data could be used to generate U.S. foodborne-disease incidence rates for persons ill enough to seek medical attention. Cost of such a system is estimated to range from $8 million to $24 million annually. An alternative may be to survey insurance records.

Improving foodborne disease surveillance will enable all participants in food production and consumption (industries, consumers, and governments) to reach a consensus on the magnitude of foodborne illnesses and deaths caused by various pathogens and to set goals for improved food safety. Such surveillance also will facilitate (1) identification of foods implicated as vehicles for pathogens, (2) determination of possible control points for specific pathogens, (3) the analysis of costs and benefits of controls at specific locations, and (4) implementation of intervention methods for specific pathogens (Figure 7.1).

Surveillance of Food Establishment Workers

A number of approaches to detecting infected workers and preventing them from contaminating foods have been taken by health and food regulatory agencies throughout the years. These approaches include medical histories, physical examinations, blood tests, x-rays, and feces examinations for parasites or bacterial pathogens, e.g., *Salmonella* and *Shigella*. Recently, some citizens have shown interest in returning to these practices primarily because of the concern about transmission of AIDS. Each practice, however, is significantly limited (World Health Organization, 1989), and none seems cost effective.

Medical histories may indicate previous illnesses in which a carrier state may still exist yet a disease

Table 7.1. Home, food service establishment, and food processing plant factors contributing to the occurrence of 1,080 outbreaks of foodborne disease that resulted because of mishandling and/or mistreatment of foods in the United States from 1973 to 1982 (adapted from Bryan, 1988b)

	Homes (345 outbreaks)		Food service establishments (660 outbreaks)		Food processing plants (75 outbreaks)	
Contributing factor	Number[a]	Percent[b]	Number[a]	Percent[b]	Number[a]	Percent[b]
Contamination						
Contaminated raw food/ingredient	145	42	58	9	14	19
Food/ingredient obtained from unsafe source	99	29	42	6	5	7
Colonized person handling implicated food	34	10	160	24	8	11
Toxic plants mistaken for foods[c]	24	7	1	< 1	—	—
Toxic containers or pipelines[c]	12	4	23	4	1	1
Cross contamination	11	3	31	5	1	1
Intentional additives (e.g., monosodium glutamate)[c]	8	2	13	2	5	7
Incidental additives[c]	3	1	9	1	6	8
Contaminated water	2	< 1	2	< 1	1	1
Improper cleaning of equipment/utensils	1	< 1	38	6	8	11
Poor dry-storage practices	1	< 1	—	—	—	—
Faulty sealing	1	< 1	—	—	—	—
Fly contaminated food	1	< 1	—	—	—	—
Improper dishwashing/contamination after dishwashing	—	—	1	< 1	—	—
Microbial growth during germination of seeds	—	—	—	—	1	1
Post processing contamination	—	—	—	—	3	4
Soil/fertilizer contamination[c]	—	—	—	—	1	1
Survival						
Inadequate cooking/canning/heat processing	108	31	29	4	20	27
Improper fermentation[d]	16	5	—	—	—	—
Inadequate reheating	12	4	130	20	—	—
Inadequate acidification[d]	2	< 1	—	—	—	—
Growth						
Improper cooling	77	22	366	56	11	15
Lapse of 12 or more hours between preparing and serving	44	13	203	31	1	1
Improper hot holding	11	3	107	16	2	3
Use of leftovers (also lapse of 12 or more hours between preparation and serving)	9	3	31	5	1	1
Inadequate drying	1	< 1	—	—	1	1
Inadequate preservation[d]	1	< 1	—	—	—	—
Improper/inadequate thawing	—	—	6	1	—	—

[a]Number of outbreaks to which this factor contributed. Many outbreaks involved more than one contributing factor.
[b]Percentage of outbreaks to which this factor contributed. Percentages exceed 100 because multiple factors contribute to single outbreaks.
[c]These factors are not due to foodborne pathogens and therefore are not the focus of this report.
[d]These factors may lead to survival and also permit growth. They were categorized in this table, where they are considered to have the more common or fundamental contribution.

Table 7.2. Data needed for estimating microbial health risks (Roberts and Smallwood, 1991)

Data need	Possible solution	Likely cost
Better recording of existing data	Expand CDC's passive laboratory based reporting from 9 foodborne microbial pathogens to about 30	About $500,000/yr (Expanding the use of tests by state laboratories would increase costs more.)
	Expand CDC's laboratory-based reporting to make surveillance active in selected counties (sentinel counties)	Additional $1 million/yr
Better demographic data on who becomes ill	Study various methods of making reporting active and estimate likely costs and benefits of increased identification of cases	About $75,000
Increased knowledge of risk factors	Study individual susceptibilities as well as food handling and consumption practices for people becoming ill and control groups	About $500,000/pathogen
Increased knowledge of disease severities	Increase the number of pathogens investigated in depth with surveys of people becoming ill from specific foodborne pathogens	Each survey may cost about $100,000–$200,000
Increased knowledge of deaths from foodborne sources	Expand the sentinel county survey to include all U.S. counties for a few selected pathogens to develop a solid baseline on foodborne deaths	About $1 million/pathogen for passive surveillance, and much more for active surveillance
	Study improving the identification of foodborne deaths in the National Death Index by improving entry of laboratory test data, by revising the death certificate to ask specifically for laboratory data	About $300,000
Increased knowledge of hospitalizations caused by foodborne pathogens	Study improving identification of foodborne pathogens in the National Hospital Discharge Survey (NHDS) by (1) examining a sample of the 150,000 hospitalizations under ICD–9 "008–unspecified intestinal infections" to see if medical records contain laboratory data, (2) examining septicemia/bacteremia records for 1 yr to determine if foodborne pathogens are involved, (3) estimating the cost of revising the face sheet for entry of NHDS data to include laboratory data and where sample was taken (blood, stool, cerebrospinal fluid), and (4) comparing state systems	Unknown, but likely to be less than $200,000/study
Quantification of chronic conditions caused by foodborne pathogens	Review the literature and estimate the likelihood that foodborne pathogens are important in certain chronic disease syndromes such as reactive arthritis, neurological disorders, cardiac dysfunction, food allergies, gastritis, kidney and liver dysfunction, etc.	Literature review about $100,000, original reseach more costly

Figure 7.1. Foodborne disease surveillance and intervention points.

condition may be diagnosed. Blood tests usually are done to detect venereal diseases or HIV carriers; skin tests and x-ray examinations, to detect tubercular infections. These infections are not transmitted via food. Other than in regions in which certain bacterial pathogens are quite prevalent, routine examinations of stools for pathogens generally would yield negative results. Furthermore, the information may engender a false sense of safety. Many microorganisms transmitted by foods—*Bacillus cereus*, *Campylobacter jejuni*, *Clostridium botulinum*, *C. perfringens*, pathogenic *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Vibrio cholerae*, non-O 1 vibrios, *V. parahaemolyticus*, *Yersinia enterocolitica*, and intestinal viruses—seldom are sought during routine examination of specimens from food workers. Epidemiological data indicate that the source of *Salmonella* causing outbreaks of foodborne salmonellosis usually is raw foods of animal origin rather than persons excreting *Salmonella*. The role of asymptomatic carriers is of secondary importance in transmission of *Salmonella*, and screening for them has a high cost-to-benefit ratio. Food-handler examination programs that seldom reveal a carrier or a positive stool culture often lead administrators to believe mistakenly that they are protecting the public or safeguarding the food supply.

Surveillance of Feeds, Ingredients, and Foods

Foods sometimes are sampled and tested to evaluate their safety in regard to a variety of items including presence or number of pathogens, number of microorganisms or amount of metabolites indicating the possible presence of pathogens (indirect, indicator-approach), condition of containers, temperature, pH, and/or water activity. Foods may be sampled at ports-of-entry, at harvest, during storage, at critical stages of processing, at completion of processing in plants, in retail stores, at markets, or in food service establishments. The laboratory is an essential resource for a food safety program.

Although surveillance of foods is expensive and time consuming, it has provided a great deal of useful information including improving our understanding of the microbial ecology of foods, verifying control procedures, and identifying hazardous lots of food. It is limited statistically by the number of samples analyzed; interpretation of data therefore must be done with care. Contaminants at times are nonuniformly distributed. This is especially true when a small population of contaminants is present. When no positive samples are found, contaminants are not detected in the samples collected and tested; yet the lot may contain contaminants. Carefully designed statistical sampling plans are critical (International Commission on Microbiological Specifications for Food, 1986). Such plans become relatively stringent when (1) large numbers of samples are taken, (2) large amounts of each sample are tested, (3) multiple culture media are used, (4) multiple criteria are used in the limits, e.g., the three-class plan, (5) limits are low, (6) tolerances are low or absent, and (7) samples are taken where most contamination occurs. Testing identifies defects and may indicate but not identify where the contaminations occurred or where the process failed. Moreover, testing usually requires a few days, and by the time results are available, foods often have been eaten or shipped.

End-product microbiological testing is used in conjunction with monitoring the process (surveillance of operations) to evaluate the safety of foods. The value of microbiological testing of raw foods is constrained because the results rarely correlate strongly with the risk of illness. This is so because food likely will be cooked and multiple food processing or handling errors can occur before illness results. Microbiological criteria for ready-to-eat foods have been useful in protecting public health (National Research Council, Food and Nutrition Board, 1985).

For *Listeria monocytogenes*, the U.S. regulatory policy of zero tolerance in all ready-to-eat foods has been questioned (Doyle, 1991b). This microorganism is widespread in the environment and probably is ingested frequently through environmental exposure. Only a limited population is at risk of contracting listeriosis. As in other countries, e.g., Germany and Canada, microbiological criteria that allow tolerance could be considered for this pathogen. Thus, small populations of the microorganism in foods would be tolerated.

Indicator microorganisms in surveillance programs have been useful (1) to detect potential human or fecal contamination, (2) to detect possible presence of pathogens, (3) to detect post-heat process contamination, and (4) to assess microorganism number, microbiological activity, or sanitary quality. If a relatively limited spectrum of economical and rapid laboratory tests is used, properly selected and applied indicator microorganisms may provide a broad spectrum of knowledge about food quality and safety. However, reliable indicator microorganisms or classes of microorganisms do not exist for certain pathogens, a notable example being viral contaminants in

harvesting waters for seafood. Lack of useful indicator microorganisms may be due to the unique presence of the pathogen in food or to our lack of knowledge about the ecology of microorganisms in the environment, including the food chain.

Surveillance of Physical Facilities and Equipment

History teaches that certain facilities—potable running water, plumbing systems free of cross-connections and of back-siphoning potential, toilet facilities, lavatory facilities, and safe sewage disposal systems—are essential for preventing contamination and for promoting personal hygiene of workers in food establishments. Today in the United States, few outbreaks implicate deficient facilities. Recurrence of these problems must be guarded against because transmission of diseases by such routes can be reestablished. In addition to the traditional surveillance activities, equipment should be designed and arranged to reduce the possibilities of cross-contamination from raw foods to foods receiving no further heat processing.

Inspection can be done neither frequently nor thoroughly enough to provide the degree of food safety desired by processors and preparers of foods and by the public. Furthermore, inspections may be done at times when either high-risk foods are not being prepared or critical processes are not being done; hence, factors critical to food safety may be overlooked. Some inspectors fail to distinguish between factors critical to food safety and those that are purely aesthetic or trivial. Laws and regulations seldom indicate the relative importance of specific items; hence, many interpretations are left to the discretion of an inspector.

Surveillance of Operations from Farm to Food Preparation

The factors in homes, food service establishments, and food processing plants, which contributed to 1,080 documented outbreaks of foodborne illness in the United States from 1973 to 1982, are detailed in Table 7.1. Review of these data indicates that cooling of foods (leaving foods at room or warm outside temperatures and attempting to cool large masses of foods in large containers) is the most important factor contributing to foodborne disease. Other frequently occurring factors include use of a contaminated raw food or ingredient, preparing foods 12 hours or more before serving, inadequately reheating cooked foods, inadequately cooking or otherwise heat processing foods, colonized persons' touching foods not subsequently heated, and improper hot holding of cooked foods. Many items which are usually part of sanitary inspections of food handling facilities never have been cited; hence, they are of negligible significance. The food safety emphasis should be on processes to which foods are exposed as well as on physical facilities.

At present, the best way to ensure food safety is by continual surveillance of food production, food processing, and food service operations. Emphasis should be on (1) hazards associated with sources of contamination to which foods are exposed, modes of contamination, and effects of the process to increase or to decrease the level of that contamination; (2) probability that microorganisms or toxic substances survive processing or process failure; and (3) chances that bacteria or fungi multiply during processing or storage. Risk assessment should be applied to enhance our understanding of the cost-to-benefit ratio of this strategy. The HACCP system (International Commission on Microbiological Specifications for Foods, 1988; The National Advisory Committee on Microbiological Criteria for Foods, 1992) provides a rational and contemporary approach to decrease the risk of foodborne illness. The seven steps or principles in HACCP are as follows.

1. Identifying hazards (contamination, survival of pathogens and toxins, and multiplication of microbes) and assessing severity of hazards and risks.
2. Determining critical control points required to prevent or to control the hazard(s) identified. A *critical control point* is an operation (practice, procedure, process, or location) at or by which preventive or control measures can be exercised that will eliminate, prevent, or minimize (a) hazard(s).
3. Implementing effective preventive and control measures and specifying criteria (or critical limits) indicating whether an operation is under control.
4. Monitoring each critical control point to evaluate whether it is under control. Systematic observation, measurement, and/or recording of significant factors for prevention or control of hazards are involved.
5. Taking appropriate and immediate corrective action whenever the monitoring results indicate that criteria established for safety at a critical

control point are not met, i.e., that the operation is out of control.

6. Establishing effective recordkeeping procedures documenting the HACCP system.
7. Verifying by either supplemental tests or record reviews (a) whether the HACCP system is in place, (b) that appropriate critical control points have been designated, (c) that they are being monitored effectively and properly, and (d) that appropriate action is taken whenever criteria are not within specified limits. Hence, verification evaluates whether the HACCP system is functioning as planned.

The HACCP approach can be applied to foods during production and harvest, during distribution and holding, during processing, during display at retail establishments, and during preparation and awaiting use in food service establishments. It, however, is not ideal for addressing problems occurring in home food handling and preparation. When properly applied, the HACCP approach offers a high level of assurance of food safety to persons concerned with food control, to those processing and preparing foods, and to the public. Hence, it is a desirable alternative to the more traditional control options, which sometimes are ineffective or inefficient.

Three goals of the HACCP concept include (1) preventing or delaying growth of pathogens occurring in foods, (2) eliminating or reducing pathogen numbers, and (3) reducing foodborne pathogen initial load and minimizing subsequent contamination (Figure 7.2). The third goal may be combined with either of the first two. Preventing or delaying growth may be achieved by appropriate storage (time and temperature), acidification, lowering water activity, and/or use of preservatives or preservation processes, for example. Reducing numbers could be achieved by use of appropriate thermal processing, cooking, acidification, fermentation, and other processing or handling procedures. Reducing initial numbers or subsequent contamination could be achieved by reducing contamination at the farm or growing site, harvesting or securing foods from reputable sources/locations, and avoiding cross-contamination, for example.

Application of the HACCP concept is somewhat complex. Conducting hazard analysis and determining critical control points require the input of trained specialists supported by adequate laboratory services. Because (1) the concept is simple yet the application is relatively complex and (2) the program requires daily attention, there is a potential for improper implementation and false security. Monitoring of critical control points and verification may require laboratory services or specialized equipment. Currently, microbiological testing is not a primary component of most HACCP plans because response time is too long for decision making. If, however, rapid microbiological methods become available that could be applied on-line, they would be useful components of future HACCP programs.

The HACCP concept is rational because it is based on historical data about causes of illness and spoilage. It is comprehensive because it relates to inputs, e.g., water and feeds, ingredients, processes, and subsequent product uses and can be applied at any or at all links of the food chain. It is continual because problems are detected when they occur and action is tak-

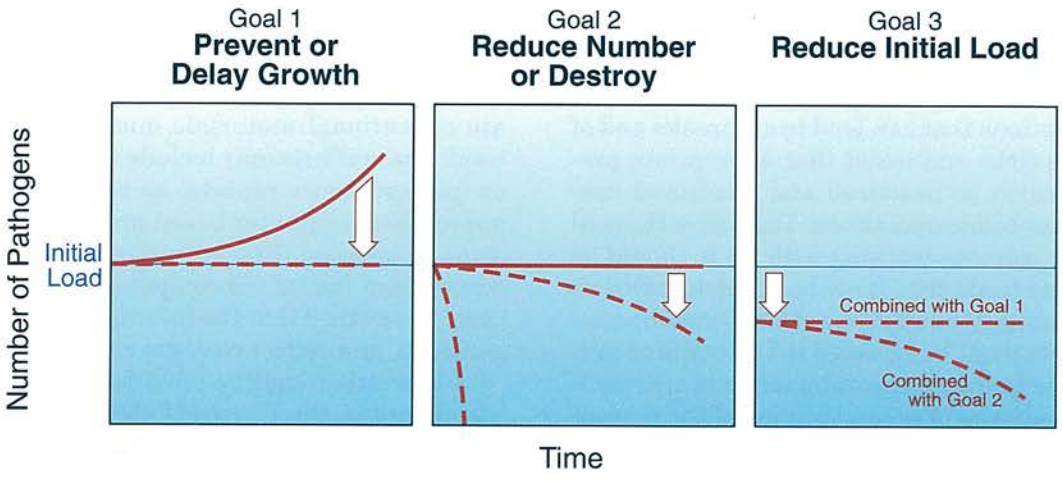

Figure 7.2. Possible Hazard Analysis Critical Control Point (HACCP) goals.

en for correction. It is systematic because it is a thorough plan covering step-by-step operations and procedures. At present, the HACCP system is the best means of ensuring appropriate food handling in food processing and food service operations and, therefore, of providing assurance that foodborne illness will not result. It is the "state of the art and science" of food safety and will reduce risks greatly wherever properly implemented and maintained.

In some instances, a HACCP plan to *prevent* contamination will be most cost effective; in others, one to *reduce* pathogens through pasteurization or irradiation will be, for example (Figure 7.2). What is needed is careful evaluation of each HACCP plan to determine whether public health protection benefits are worth the costs. Given the high cost of laboratory tests, a HACCP plan based exclusively on laboratory testing easily could be devised that would be so expensive as to offset likely public health protection benefits. In addition, because of the often dispersed distribution of pathogens in many foods, laboratory testing can be an unreliable and misleading indicator of food safety.

Training

Specialists in food safety must understand the epidemiology of foodborne diseases and the microbial ecology of foods so that measures to prevent these diseases can be devised or selected and given appropriate priority. These individuals also must have skills to investigate outbreaks of foodborne diseases, to use the data gathered in preventive programs, and to set program priorities. Technically trained professionals must be prepared to develop and to verify a HACCP system.

Food establishment managers have the primary responsibility for preventing conditions that can lead to outbreaks of foodborne disease within their establishments (Table 7.1). They must be aware of the kinds of operations that can lead to outbreaks and of their relative risks and insist that appropriate preventive measures be practiced and monitored routinely during or before operations. To achieve the goal of food safety, persons working with foods should be convinced that foods that have been mishandled or mistreated can lead to outbreaks of foodborne disease. These concepts must be stressed in the training program. Because food service establishments are implicated in the majority of cases, training of the personnel in these establishments is particularly critical. This task is difficult because personnel turnover tends to be high and the educational level, skill, and compensation typically are low.

Food establishment workers need to know how to do their jobs so that they will not contribute to the contamination of foods and so that either the microbial contaminants entering foods are killed or their multiplication is inhibited. Hence, through training, employees must develop an understanding of the hazards and skill in monitoring critical control points and an appreciation of their significance. The continued implication of food service workers in transmission of hepatitis illustrates both the importance and difficulty of successful training.

Education

A large number of foodborne illnesses can be attributed to food handling errors that occur in the home (Table 7.1). Because of the diffuse nature of these outbreaks, public education is one key to their prevention. A scientifically literate public would be well equipped to understand the principles of safe food handling and risk-benefit decision making. Food science, food safety, and public health provide an excellent context for improving overall scientific literacy of the public since most people find these topics interesting because of their practical importance to everyday life. The public should be educated to understand that our goal must be risk minimization and that zero risk is not attainable relative to food safety. An educated public could become involved in a dialogue addressing what responsibilities fall to individuals, to the food industry, and to the government relative to their preferences regarding enhancing food safety.

Public education regarding foodborne disease risks and control must begin with teachers and progress to pupils in primary and secondary schools and beyond. The adult public must continue to be educated in the important hazards and risks associated with food purchase, preparation, and storage. Appropriate educational materials must be developed and used. These efforts may include traditional approaches (posters, news reports) as well as more modern approaches (computer based problem solving educational packages, dissemination of information into schools and homes via computer networks). In each case, it is critical that the information be credible and accurate, and reflect realistic risk analysis.

A new safe-handling label for meat has been implemented in the United States. This instructional label contains information about storing and thawing meat, avoiding cross-contamination, cooking, and properly refrigerating leftovers. This should improve

the handling of meat in the home and address many of the primary factors contributing to foodborne illness (Table 7.1). It thus should reduce the incidence of meatborne disease.

Regulatory Approaches

The USDA and the FDA share responsibility for food inspection at the federal level and have primary responsibility for inspecting imported food and domestic food production (Federal Meat Inspection Act of 1906, Amended 1967; Federal Poultry Products Inspection Act of 1957, Amended 1968; Federal Food, Drug and Cosmetic Act, 1938). The USDA/FSIS has primary responsibility for meat and poultry; the USDA and the FDA share responsibility for egg, milk, and grain inspection; and the FDA has primary responsibility for all other foods in interstate commerce including processed foods, fresh seafood and game meats, and foods served on interstate public conveyances, such as airlines and trains. States and cities have primary responsibility for food safety at dairy farms, supermarkets, restaurants, and nursing homes and may certify food safety training for people working there. In 1992, the FDA devoted about 255 staff years to inspecting 53,000 food establishments, while the FSIS devoted 9,000 staff years to inspecting 6,100 food processing plants (Gore, 1993).

The FDA and the FSIS have different approaches to regulation. The FDA has emphasized voluntary adoption of GMPs, the Pasteurized Milk Ordinance, etc. by states and firms. The FDA uses random inspection on occasion, relies on firms for voluntarily recalling contaminated products, and lacks FSIS' mandatory record-keeping requirements except in the case of low-acid canned foods. The FSIS and the FDA can seize (domestic) or detain (imported) suspect or known contaminated products. The FSIS has in-house inspectors in all slaughterhouses who inspect every carcass. As reflected in the design, inspection is intended primarily to ensure that diseased carcasses do not enter the food supply. The problem is that pathogens are not detectable by sight, touch, or smell, although product safety is enhanced by inspection because inspectors ensure that animals' intestines are not severed, thus minimizing contamination of the carcass with intestinal microorganisms. The FSIS, however, seldom recalls products and seldom tests carcasses or meat products for pathogens.

Both the FDA and the FSIS are moving toward more risk-based inspection, such as the HACCP, and integration of some rapid tests for pathogens into their food safety monitoring. At this writing, there are proposals in Congress and in the Executive Branch for reorganizing food safety regulatory responsibilities. Under Vice President Gore's recommended streamlining, inspection would be consolidated into the FDA.[13] Several Congressional bills further elevate food safety regulation by creating a food safety regulatory agency.

Development of rapid, low-cost methods may allow future on-line monitoring of pathogens, but application of methods and knowledge will be complex because the interpretation of microbiological data from raw products generally is controversial. Since microbiological specifications regarding the presence of low numbers of pathogens in foods such as raw meat and poultry do not exist, knowledge of pathogen presence would be meaningless from a regulatory standpoint at the present time. Development and implementation of rapid microbiological tests on line should not be considered a panacea for improved food safety inasmuch as opportunities for contamination will continue to occur after harvesting/slaughtering and processing and during distribution, preparation, and storage.

The HACCP system, if properly implemented and continuously practiced, offers a valuable means of institutionalizing safe food practices. Both the USDA and the FDA have incorporated HACCP principles in proposed future regulations. Congress must provide regulatory agencies with adequate resources and staff directed to ensure food safety, and regulatory laws must be based on good science. Food safety legislation without this basis inevitably will needlessly increase the cost of food in the United States and may prove detrimental to the cause of public health.

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[13]"The FDA would handle all food safety regulations and inspection, spanning the work of the many different agencies now involved. The new FDA would have the power to require all food processing plants to identify the danger points in their processes on which safety inspections would focus. Where and how inspections are carried out, not the number or frequency of inspections, determines the efficiency of the system.

The FDA would also develop rigorous, scientifically based systems for conducting inspections. Today, we rely, primarily, on inspection by touch, sight, and smell. Modern technology allows more reliable methods. We should employ the full power of modern technology to detect the presence of microbes, giving Americans the best possible protection. Wherever possible, reporting should be automated so that high-risk foods and processors can be found quickly.

Enforcement powers should be uniform for all types of foods, with incentives built in to reward businesses with strong safety records" (Gore, 1993).

Future Trends and Food Control Opportunities

Three trends will lead to provision of a safer food supply: greater demand for food safety, continuing scientific advances in our knowledge of the pathogens and how they are transmitted in the food chain, and increased efficiency in providing safer food.

Demand for food safety regulations may grow due to changes in food demand and demographics. An older population will be more willing to pay for health attributes of food (Kinsey, 1994). The growing popularity of convenience foods further reduces consumers' control over food preparation and may alter the nature of foodborne illness risks. A growing population of high-risk consumers means that for a given number of pathogens in food, more people are likely to get sick.

New scientific advances increase our options in producing safer food. Our ability to identify foodborne pathogens causing acute and chronic illnesses in humans is improving, as is our understanding of the relationship between pathogens and production, processing, transportation, and retailing practices. Continued development of faster, cheaper, more specific, and more sensitive tests for pathogens improves detection of contaminants in foods and permits more statistical testing.

Increased efficiency in providing safer food is resulting from (1) better risk assessment databases' being developed (Berkelman et al., 1994; Steahr, 1994) and (2) increased use of a systems approach, such as HACCP, to identify where pathogens or their toxins come into the food chain (Figure 7.1) and to reduce the likelihood of foodborne illness. Increased evaluation of the benefits and costs of control at various control points will lead to an improved understanding of the most efficient intervention points. Vice President Gore's *Report of the National Performance Review* advocates using incentives to reward firms with strong safety records and enforcement to punish firms with poor performance. Economic incentives are an efficient mechanism for sending signals to the market and encouraging production of products with desirable characteristics, such as safety. In the short run, firms can increase testing for contaminants and buy from suppliers with low levels. In the long run, research on new production practices should be encouraged as well as research to allow development of new, safer products. Existing food safety regulations were not designed to provide market incentives for "safer" food, but rather one safety standard for all. Protecting the more vulnerable groups in each case, such as children or the elderly, may result in higher costs for the average consumer.

We are poised to make changes that will have a real, positive impact on food safety. Opportunities exist for *prevention*, *reduction*, and *destruction* of pathogens in foods. Historically, primary efforts at control have been focused on food processing and food service. Oftentimes warning consumers is sufficient; in some instances, voluntary actions by industry suffice; in others, mandating actions to reduce pathogens in a specific food may be required. New opportunities involve these areas yet include others, extending control efforts to the source (farm or sea) and to the home:

1. An educational label addressing safe meat handling has been adopted recently. This will serve as a constant reminder and as a resource to persons preparing foods in the home and will help ensure their participation in safe food handling and preparation.
2. Future labeling or package inserts may include information relative to "safer" foods for individuals in the population who are (permanently or temporarily) at increased risk for foodborne illness. Presumably, these products would be priced accordingly and consumers would be free to choose whether to alter purchasing practices based on food safety considerations. To be effective, this will require a public educated in risk-benefit decision making and who understand that the goal is risk minimization, not zero risk.
3. The rapid improvements in telecommunications and increased access to the "information highway" will provide new opportunities to bring food safety information of an educational (e.g., safe handling procedures, knowledge of high-risk populations) or decision making (risk-benefit problem solving) nature into grocery stores, restaurants, schools, or homes.
4. The HACCP approach likely will be incorporated as a regulatory approach quite soon, as well. For example, on January 1, 1994, the FDA proposed regulations to ensure the safe processing and importing of seafood that include monitoring of selected processes in accordance with HACCP principles. The USDA has drafted a new statutory proposal directly addressing the need for pathogen control in the prevention of foodborne illness and uses the process control, or HACCP, strategy to accomplish pathogen reduction.
5. Irradiation of pork and poultry is approved in the United States, and approval of the irradiation of

beef and other products may follow shortly. Consumer acceptance of this practice will improve food safety by significantly reducing pathogen numbers in raw meats (Radomsyski et al., 1994). The government should share its extensive knowledge of this subject with the public so as to further acceptance.

6. Farm-level control may be improved as we learn more about the ecologies of pathogens, including how they interact with host animals. One opportunity is to use the concept of competitive exclusion to prevent the intestines of young animals from being colonized by human pathogens (Stavric and D'Aoust, 1993; Stern and Meinersman, 1989). Research indicates that this may be accomplished by introducing the newborn animal to, for example, harmless microorganisms quite early (by adding the desired microorganisms to water or feed) so that they will establish themselves in the animal intestine. Thus, the undesirable microorganisms would be unable to compete and would be excluded. The animal no longer would be a carrier or a source of the pathogen when used in human food, given successful competitive exclusion.
7. Animal identification and traceback methods may be applied to identify the source(s) (processing facility, slaughterhouse, feedlot, or farm) of foodborne illnesses.
8. Microbiological methods are being developed at a rapid rate, and the costs of technologies generally are falling. Thus, improved, useful, rapid methods, perhaps even some that can be applied on-line (during food processing, distribution, handling), should become available continually. Many useful methods are currently available. Appropriate and expanded applications of such methods will improve our understanding of the ecology of food associated pathogens, thereby improving our control procedures indirectly if not through direct (on-line) applications.
9. The analytical tools available to epidemiologists continue to improve so that our ability to trace the microorganisms involved in a foodborne illness outbreak from person to person and from person to food handler and back to the processing location and farm will improve. Thus, our understanding of the microorganisms and their occurrence as well as our ability to select and to apply appropriate control procedures will increase.
10. Development of integrated databases regarding animal pathogens, retail food tests, and human illnesses will clarify how pathogens move through the food chain and what their human health consequences are. Such databases would facilitate consensus regarding the magnitude of the foodborne disease problem, identify the most dangerous pathogens, and aid in the development of control options by identifying food chain entry points. The CDC recently developed a surveillance strategy that includes the use of sentinel networks linking groups of healthcare providers or laboratories to a central data receiving and processing center (Bryan et al., 1994; U.S. Department of Health and Human Services, 1994).
11. Improved databases and risk assessment techniques also will aid identification of high-risk human subpopulations and high-risk foods. Specific control procedures can be developed to reduce risks by informing high-risk individuals to take precautionary actions or by devising new control procedures for high-risk foods. To augment existing databases and to increase foodborne disease reporting, innovative ideas should be explored, such as adding an e-mail address and an 800 number to telephone directories and to restaurant and fast food menus to facilitate reporting of potential foodborne diseases to local, state, and federal authorities.
12. Increasingly, economic incentives are being proposed and used to improve food safety and quality. United States dairy farmers are paid premiums for milk with low bacterial counts (total plate counts) and somatic cell counts (indicating infection) and are discounted for milk with counts above minimum levels. Dutch hog producers are field testing plans to reduce parasite levels and are receiving premium prices for compliance. Food service firms increasingly are specifying microbial levels in food purchasing contracts in the aftermath of problems with *Salmonella enteritidis* in eggs and *Escherichia coli* O157:H7 in ground beef (Roberts and Unnevehr, 1994).
13. Improvement of K–12 and adult education in areas of science, technology, and health education as well as in critical thinking skills will improve public understanding and individual ability to protect health through making informed decisions on issues that impact food safety.

It is important to capitalize on the synergism gained from appropriate research, education, and implementation relative to food safety knowledge and advancements. It is critical to continue research to generate new knowledge relative to food safety, and

to continue educational efforts to disseminate the knowledge so that it can be properly and wisely implemented by policymakers, regulators, producers, processors, food handlers, public health officials, and consumers. Informed implementation will be enhanced by honest public discussion regarding needs, expectations, and costs.

Appendix A: Acronyms and Symbols

Acronyms

AIDS	acquired immune deficiency syndrome
CAST	Council for Agricultural Science and Technology
CDC	Centers for Disease Control and Prevention, Department of Health and Human Services
COI	cost of illness, primarily medical costs and productivity losses as a result of foodborne infections
DNA	deoxyribonucleic acid
ERS	Economic Research Service, U.S. Department of Agriculture
FDA	U.S. Food and Drug Administration, Department of Health and Human Services
FSIS	Food Safety and Inspection Service, U.S. Department of Agriculture
GBS	Guillain-Barré syndrome
GI	gastrointestinal
GMP	Good manufacturing practice
HACCP	Hazard Analysis Critical Control Point
HAV	hepatitis A virus
HCl	hydrochloric acid
HIV	human immunodeficiency virus
HUS	hemolytic uremic syndrome
ICD-9	*International Classification of Diseases,* ninth edition
MMWR	*Morbid Mortality Weekly Report,* published by Centers for Disease Control and Prevention
NAS	National Academy of Sciences
NDI	National Death Index published by the National Center for Health Statistics
NRC	National Research Council, National Academy of Sciences
PSP	paralytic shellfish poison
SIS	Streamlined Inspection System
USDA	U.S. Department of Agriculture
WTP	willingness to pay (for safer food)

Frequently Used Symbols

a_w	water activity; equilibrium relative humidity/100; refers to the relative amount of water available for microbial growth or chemical reactions; water activity may range from 0 to 1
cm	centimeter
ft	foot
hr	hour
in.	inch
min	minute
μm	micrometer
yr	year

Appendix B: Glossary

Bacteria. One-celled living microorganisms with a cell wall.

Bolus. Mass of swallowed food.

Brush border. Microscopic projections, or microvilli, on the epithelial cells of the small intestine.

Chronic sequelae. Secondary, after-effect illnesses that may be of long duration.

Chyme. The partly digested food passing from stomach to small intestine.

Colony-forming unit. Used to measure bacterial populations.

Critical control point. An operation (practice, procedure, process, or location) at or by which preventive or control measures can be exercised that will eliminate, prevent, or minimize (a) hazard(s).

Cyst. Protective capsule surrounding an inactive or resting parasitic organism or enclosing a reproductive body. It is transmissible through food and is inert and resistant to the environment outside the host.

Enteric viruses. Viruses associated with foodborne disease and characterized by growth in the liver or intestinal cells and subsequent excretion in the feces.

Foodborne disease. Any illness resulting from ingestion of contaminated food.

Foodborne pathogens. Microorganisms causing illness through ingestion of food.

Host. Person eating contaminated food.

Immunocompromised, immunoimpaired, or immunosuppressed. An immune system functioning in a less than optimal manner or at an overall reduced level.

Incubation period. Time from ingestion of a pathogen until symptoms occur in the human body.

Infection. Used in this report to mean a carrier or illness state arising from a microbial or a parasitic organism that is ingested and multiplies in the host's body.

Infectious dose. The susceptibility threshold for infective or toxicoinfective pathogens.

Intestinal disease. Vomiting and/or diarrhea without respiratory symptoms.

Intoxication. The state produced by an organism that produces toxin in food that is ingested.

Invasive infection. The state produced when pathogenic microorganisms grow in, or colonize, the intestines, invading the mucosa or other tissues.

In vivo. Being or occurring within a living organism.

Large intestine. The cecum, colon, and rectum.

Lumen. The open space at the center of the gastrointestinal tract.

M cells. Lymphoepithelial cells associated with the Peyer's patches in the small intestine.

Microvilli. In this report, describes the microscopic projections on the epithelial cells of the plicae and villi of the small intestine.

Mycotoxins. Toxins produced by fungi.

Opportunistic pathogen. Microorganism that may cause disease only in special circumstances such as in a host with a weakened immune system.

Parasite. An organism living on or within an animal of another species, from which it obtains nutrients.

Protozoa. One-celled microorganisms without a rigid cell wall; their genetic material is contained in an organized nucleus. They are larger than bacteria and increase by twofold division, but only in hosts—not in foods.

Pathogens. Infectious, toxicoinfectious, or toxin-forming microorganisms causing disease.

Pepsin. A protein-digesting enzyme.

Peristalsis. Rhythmic contractions of muscles surrounding the lumen of the alimentary canal.

Peyer's patches. Lymphoid tissues in the small intestine, related to immune system

Plaque-forming units. Used to measure viral populations.

Plicae. Folds of the mucous membrane, such as that of the jejunum.

Pylorus. Closure between the stomach and the intestine, which retains materials in the stomach for exposure to hydrochloric acid and pepsin.

Risk. The probability of the occurrence of a hazard.

Sous vide. Vacuum sealed and usually cooked at temperatures below 160°F.

Stomach acidity. Low stomach pH.

Toxic dose. The susceptibility threshold for toxins.

Toxicoinfection. The state produced by an organism that produces toxin while in the intestinal tract.

Toxicoinfective microorganisms. Noninvasive, infective foodborne microorganisms that cause illness by producing toxins while growing in the human intestines.

Trophozoite. Active feeding form of a cyst, which can divide and multiply.

Villi. Projections in the lining of the small intestine.

Virulence factors. Microbial products or abilities produced by some pathogens, e.g., attachment factors enabling them to colonize the intestinal walls effectively; or extracellular enzymes, toxins, or other compounds altering permeability or damaging epithelial cells so that pathogens can invade.

Viruses. Particles too small to be seen with a light microscope yet visible with an electron microscope. Produced only within suitable living cells, that is, in a specific host species and in specific tissues within the body of the host.

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Index

Q–R

S

T

V

W–Y

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