21
Future Directions in Food Safety*

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Abstract

The recent success that the USDA Food Safety Inspection Service has had in 2003 and 2004 of reversing the steadily increasing trend in Class 1 recalls is welcomed. In agreement with those statistics are the FSIS microbiological results for *Escherichia coli* O157:H7 in raw ground beef, which also showed a decrease in 2003. But there is much work to be done in food safety and much more to achieve. It is imperative that while addressing food-safety issues, we should understand the role that the environmental microbiology, public health epidemiology, aerobiology, molecular microbial ecology, occupational health, industrial processes, municipal water quality, and animal health have on food safety. Although it is a difficult task, a concerted effort by industry, academic, and governmental researchers can accomplish the goal. Here we discuss the future directions and applications in the distribution and spread of foodborne hazards, methods for microbial detection and differentiation, intervention strategies for farm pathogen reduction, targeting waste at animal production sites, considerations on antimicrobial resistance, food-safety storage and preparation strategies, food irradiation, new and emerging food-safety hazards, and quantitative microbial food-safety risk assessment. Although this does not comprise an exhaustive list of food-safety issues, these are the areas that, we think, require considerable attention by researchers. Not only we need to strive to improve food safety through new strategies, processes, and applications, but we also need to be flexible and observant to readily handle the new and emerging food-safety problems, whether they are within our borders or global. At present, the United States has one of the safest food-safety systems in place. However, although this is not a time for complacency, our research endeavors should be designed to keep pace with the food-safety needs of the future.

1. INTRODUCTION

Thousands of people around the world die each year from contaminated food. Foods can be contaminated with microbial pathogens and toxins at all points of the food-production cycle from preharvest through postharvest as well as within the home. Pathogens that can be deadly to humans are found to reside within food animals. The US Centers for Disease Control and Prevention (CDC) reported that the outbreaks of foodborne diseases for which the etiology and transmission vehicle could be traced have resulted from foods of animal origin about 50% of the time *(1)*. The CDC estimates that foodborne disease causes approx 76 million illness cases in the United States each year. This results in approx 325,000 hospitalizations and 5000 deaths each year. The costs in terms of overall medical expenses and lost wage-productivity are estimated to be between

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From: *Infectious Disease: Foodborne Diseases*
Edited by: S. Simjee © Humana Press Inc., Totowa, NJ

US$6.5 and 34.9 billion *(2,3)*. One of the main pathogens for concern, *Salmonella*, is an important cause for human and animal diseases worldwide *(4)*, and can be serious or fatal for the elderly and immunocompromised. The CDC estimates that each year in the United States over 1.3 million illnesses and 553 deaths are caused by foodborne transmission of *Salmonella*. The cost of medical care and lost productivity due to *Salmonella* infections in the United States were estimated at $2.3 billion per year in 1998 dollars *(5)*. Pathogenic *Escherichia coli* primarily cause one of three types of infections: enteric infections, urinary tract infections, or septicemic infections *(6)*. Among the enteric *E. coli*, bacteria capable of producing Shiga toxins are of particular concern. Shiga toxins are potent protein-synthesis inhibitors capable of killing cells in picogram quantities. *E. coli* O157:H7 is the most common Shiga toxin-producing *E. coli (7)*. It is estimated that in the United States 62,000 human illnesses and 52 deaths are caused by foodborne transmission of *E. coli* O157:H7 each year *(2)*.

Increased occurrence of pathogens that cause major foodborne disease outbreaks (*E. coli* O157:H7, *Salmonella*, and *Listeria monocytogenes*) are key concerns for food producers, food processors, governmental regulators, public health officials, and consumers worldwide. These challenges have led to increased global demand for actions to improve the safety of raw and manufactured foods *(8)*. The US Department of Agriculture–Food Safety Inspection Service (USDA–FSIS) has adopted an overall food-safety strategy to reduce the risk of foodborne illness associated with pathogens such as *Salmonella* spp., *Campylobacter* spp., *E. coli* O157:H7, *L. monocytogenes*, *Clostridium botulinum*, *Clostridium perfringens*, *Staphylococcus aureus*, *Aeromonas hydrophila*, and *Bacillus cereus (9)*. In 1996, the USDA–FSIS issued a final rule that requires the meat and poultry establishments to adopt a scientific Hazard Analysis Critical Control Point (HACCP) system *(10)*. HACCP is a mandatory food system used by all food companies in the European Union *(11)*, and it is internationally recognized as being a most effective means for producing safe food *(12–14)*.

In the years following the implementation of the HACCP program, the total number of Class 1, or high risk, recalls steadily increased (Fig. 1). Then, in 2003, FSIS outlined five goals to improve the health status of consumers. This document is called "Enhancing Public Health: Strategies for the Future" *(15)*. In this document "FSIS outlined a series of new and comprehensive scientific initiatives to better understand, predict, and prevent microbiological contamination of meat, poultry, and egg products, thereby improving health outcomes for American families" *(16)*. The addition of these initiatives along with other improvements in food safety has resulted in a downward trend in the number of Class 1 recalls during 2003 and in the first half of 2004 (Fig. 1). FSIS has been obtaining microbiological results for *E. coli* O157:H7 in raw ground beef products since 1994 *(17)*. Late in 1999, FSIS introduced new methods that further increased the sensitivity of the microbiological tests. Table 1 shows the overall results of the determinations for the years 2000–2003. The percent positives average around 0.8% from the years 2000–2002, but declined to 0.3% in 2003 *(17)*. These results correlate well with the observed recalls over this period. Another indicator that the FSIS scientific policies and programs have improved food safety is the data from late 2003 that show a 25% drop in the percentage of positive *L. monocytogenes* regulatory samples compared to those of the year 2002, and a 70% decline compared to the years prior to the implementation of the HACCP program *(16)*.

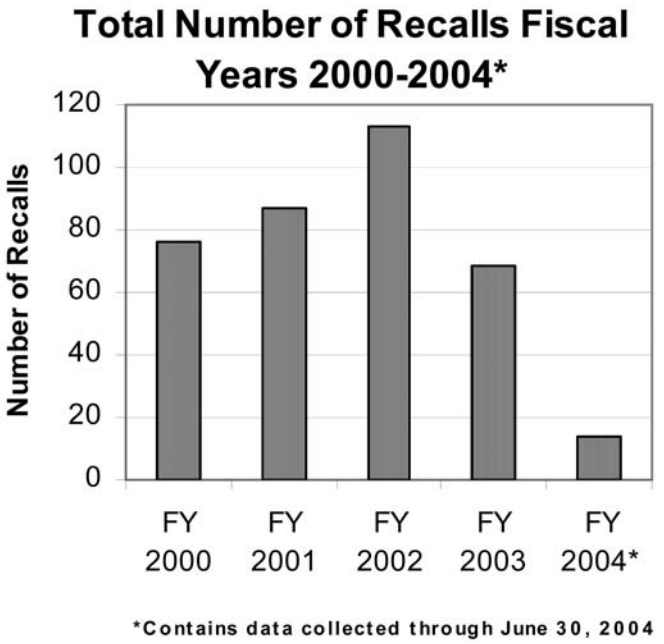

Fig. 1. Total number of recalls during the fiscal years 2000–2004 *(16)*.

Table 1
Microbiological Results of Raw Ground Beef Products Analyzed for *E. coli* O157:H7, 2000–2003 *(17)*

Year	No. of samples	No. of positives	%Positives
2000	6375	55	0.86
2001	7010	59	0.84
2002	7025	55	0.78
2003	6584	20	0.30

These FSIS results are very promising and the contamination trend appears to be in the right direction. But let us make no mistake that there is plenty to do in food safety. The recent trends shown above by FSIS are just a beginning. We definitely want to see recall rates hovering around 0%, and contamination rates at zero. Are these rates achievable? Can these rates be maintained?

Many of the pathogens that can cause widespread disease outbreaks among the human population are transmitted through surface and groundwater and may ultimately end up on food, either through irrigation water, through contact or through contaminated processing water. Given the multiple routes through which humans can contaminate the environment as well as be exposed to microbial pathogens, it is impossible or illogical to separate food-safety principles from the environmental quality or from the public health principles (Fig. 2). It is also extremely critical to emphasize that to address food-safety issues holistically, a clear understanding of environmental microbiology,

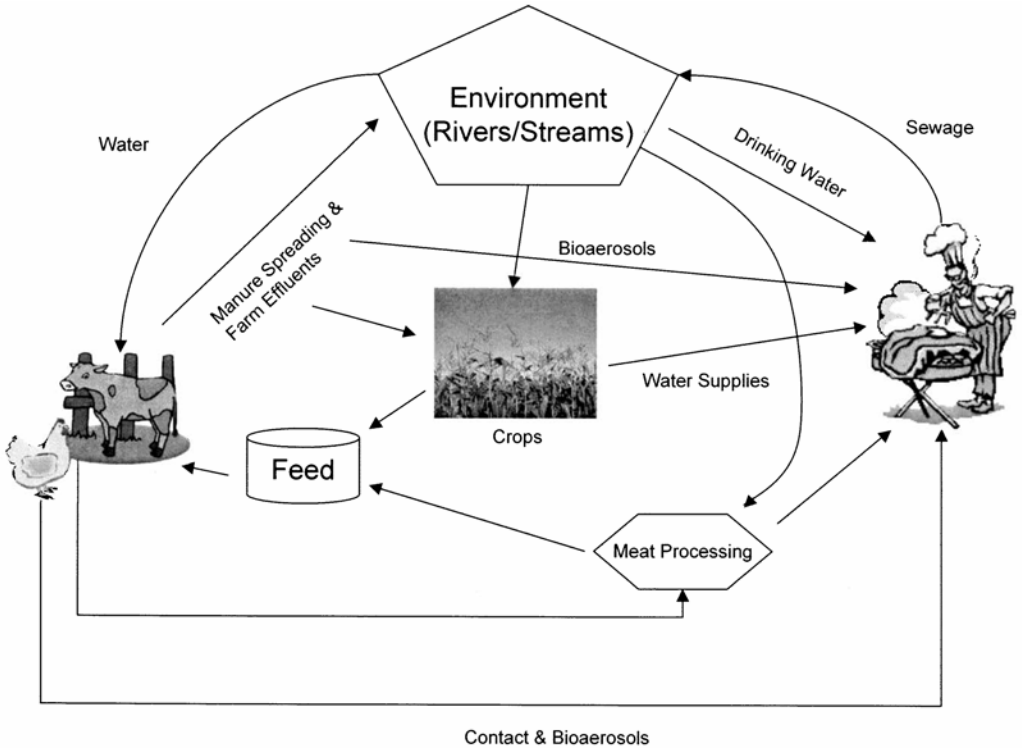

Fig. 2. Spread of microbial pathogens among food, environment, wastes, and humans.

public health epidemiology, aerobiology, molecular microbial ecology, occupational health, industrial processes, municipal water quality, and animal health are needed (Fig. 3). Otherwise, the solutions that are devised and the outcomes that are achieved can be seriously compromised. In the mean time however, we need to be adamant about learning more about host–pathogen interactions, distribution and spread of foodborne hazards, including handling the glut of manure buildup at animal production facilities, antimicrobial resistance involvement from prescription and on-farm abuse, and the abuse because of the incorporation of antibiotics in a myriad of household products available in the open market. We must also strive to improve and simplify verification tests, improve decontamination strategies and on-farm pathogen reduction strategies, be fully prepared to handle the new and emerging food-safety hazards, and be more analytical in addressing microbial food-safety issues. Last but not least we need to come up with a good plan to impart and implement food-safety storage and preparation strategies for the producer, retailer, food service operation, and the consumer. Some of these areas will be highlighted in this chapter. These areas as well as others have been discussed in detail in other recent publications *(18,19)*.

2. DISTRIBUTION AND SPREAD OF FOODBORNE HAZARDS

The scientific community, the regulatory community, and the general public need to realize that is impossible and incorrect to cubbyhole food safety separately from environmental quality and public health. As shown in Fig. 2, the organisms that are of concern

Fig. 3. Interrelationship of food safety with other disciplines.

to food safety find their origins in the environment, in farm animals, and in humans. Organisms are transmitted between humans, animals, the environment, and foods through air, water, soil, and equipment routes. Multiple disciplines and factors ultimately impact the safety and quality of foods (Fig. 3). Although the transmission of hepatitis A infection may be decreased by vaccinating food-service workers, there are other routes of hepatitis A transmission that are extremely difficult to control. The safety in food-service operations can depend highly on the incoming food ingredients. Enteric viruses such as hepatitis A (HAV) can get into the food chain through contaminated irrigation water or wash water. In 1988, 202 cases of HAV were reported in one outbreak, and upon investigation it was traced back to commercially distributed lettuce. Contamination in the lettuce was found to be prior to local distribution *(20)*. In 2003, approx 555 people were infected with HAV at one restaurant, resulting in three deaths, through contaminated green onions which was traced back to contamination in the distribution system or during growing, harvesting, packing, or cooling *(21)*. Pathogens such as *L. monocytogenes* find ecological niches (to survive) within food-processing facilities in locations such as within drains and on food-handling equipment. Thus, the design, the material, and the ability to clean and disinfect the equipment have significant impacts on our ability to control this pathogen.

In the future, improved analytical methods will lead to the identification of the environmental reservoirs of a number of pathogens that are relevant to food safety. Improved surveillance and tracking studies will lead to the identification of many of these pathogens that could be classified as emerging or re-emerging pathogens. Studies on the biotic and abiotic factors that influence the emergence of these pathogens will gain increased attention worldwide. The influence of global climate change on infectious disease trends will be another intensively studied area. The fate of newly identified pathogens in air, water, and soil would need to be explained to identify the environmental management strategies to control these pathogens. Improved waste-handling and waste-treatment

systems for both municipal and animal wastes have to be developed to minimize or eliminate infections from pathogens such as SARS. Water treatment technologies incorporating UV disinfection, reverse osmosis, chlorine dioxide, and ozone need to be evaluated for specific applications on the farm and in postharvest processing applications.

3. METHODS FOR MICROBIAL DETECTION AND DIFFERENTIATION

The detection of specific microbial pathogens is expected to increase worldwide. In 1999, the United States food industry performed as many as 144 million microbiological tests *(22)*. These numbers were 23% higher than what was observed in the preceding year. It must be emphasized that though the number of microbiological tests were indeed significant, only approx 26% of these tests were pathogen-specific tests. Regulatory pressures on the food industry such as the "zero tolerance" of pathogens like *L. monocytogenes* and *E. coli* O157:H7 have been responsible for the increase in tests to detect these organisms *(23)*. Even though there are commercial diagnostic assays to detect many of the key foodborne bacterial pathogens, there are no commercial kits to detect enteric viruses in food. This is an unfortunate situation given that viruses account for over 65% of known foodborne illnesses in humans. A variety of food items such as fresh produce, frosted bakery products, infected food-handlers, and shellfish are known to have transmitted viral infections to the human population *(24–26)*. Methods are urgently needed to process the food samples to extract the viruses out of the samples, concentrate the viruses, and ultimately detect the viruses without interference from the sample matrix. Current methods to detect enteric viruses using tissue culture are extremely time-consuming, labor intensive, and are consequently expensive. Qualitative molecular methods that provide only a cursory positive/negative result for the presence of enteric viruses in food may have only limited applicability given the potential to detect noninfectious virus particles. There have been a few reports on the detection of infectious virus particles using molecular methods. These methods need to be rigorously tested in multiple laboratories and on different types of samples to prove their ultimate utility for the food industry.

Critical issues related to the use of molecular methods for pathogen detection in the food industry include choosing the appropriate sample volumes to be tested, sample concentration and purification procedures, and ultimately regulatory acceptance of the molecular methods. Molecular methods will find increasing applications especially for microbial risk-assessment studies. The USDA and the FDA must deal with the issue of re-emerging organisms and have the responsibility of identifying and prioritizing the critical microbial contaminants in foods. Using indicator organisms in lieu of specific pathogens can be fraught with limitations. Although spectacular breakthroughs have been achieved in terms of biosensors for pathogen detection, much work still remains to be done with respect to the first step in detecting pathogens, namely sample processing. The processing has to be extremely efficient at recovering small numbers of organisms on food samples but also has to be amenable to downstream applications such as molecular assays (i.e., PCR, quantitative PCR, or biosensors) without any interference from the sample matrix. PCR is ideally suited for the food industry. It may provide more effective product quality monitoring and prevent costly recalls. Even though molecular methods will not totally replace the conventional microbiological assays, the future molecular methods can allow for faster, more sensitive, and more characterization

capabilities. This will entail an increased awareness of QA/QC as it pertains to molecular methods and a trained workforce that can keep up with the rapidly changing technologies.

Differentiation among foodborne pathogens is accomplished in two main ways. The traditional phenotypic methods are one way of identification and classification of bacteria. The second way uses genotypic or other molecular methods *(27)*. Many of the best discriminatory methods, like pulse-field gel electrophoresis (PFGE), take days to conduct. The CDC supported PulseNet which relies on PFGE fingerprinting is considered the golden standard for epidemiological tracking. In the future, methods to differentiate bacteria strains will be developed that are rapid, reproducible, and hopefully automated. The current 16S rDNA-based fingerprinting method (termed Riboprinting), though automated and sophisticated, is still far from being as discriminatory as PFGE. It is critical to improve and devise new discriminatory tools. Methods based on multilocus variable number tandem repeat analysis (MLVA) show promise. This method has been able to distinguish among *E. coli* O157:H7 isolates that appear homogeneous by PFGE *(28,29)*, and distinguished between *Bacillus anthracis* isolates *(30–32)*. It is the new methodologies, such as this one, that will help us to move forward into the future with more discriminatory results and rapid response time. In the final analysis, however, it will be the regulatory and liability pressures that will ultimately dictate whether or not, and to what extent the food industry will adopt molecular methods *(23)*.

4. ON-FARM PATHOGEN REDUCTION INTERVENTION STRATEGIES

Because the farm is the initial location for the foods of animal origin, it is on the farm where the improvement of food safety of animal origin needs to begin. New additional food-safety interventions should be developed to decrease pathogen contamination during livestock and poultry production. A number of products have been developed using the strategy known as competitive exclusion (CE). Competitive exclusion is the process of using microbial cultures to out compete pathogenic bacteria. A defined culture having 29 nonpathogenic bacteria was developed that decreased the prevalence of *Salmonella* in chicks *(33,34)*. Another CE product was developed using an undefined culture that decreased the prevalence of *Salmonella* in poultry *(35)*. Currently, a CE culture to be used in swine is under development. In vitro studies using a continuous flow culture in chemostats demonstrated that the culture designated RPCF decreased *Salmonella enterica* serovar Choleraesuis, *E. coli* F-18, and *E. coli* O157:H7 within 24 h post-inoculation, and *S. enterica* serovar Typhimurium was reduced by 48 h post-inoculation *(36)*. The RPCF culture reduced *Salmonella* serovar Choleraesuis colonization in early-weaned pigs *(37)*. The use of RPCF to protect suckling neonatal pigs against infection with enterotoxigenic *E. coli* resulted in significant reduction of *E. coli* compared to the controls *(38)*. During field trials, the RPCF culture reduced the disease associated with enterotoxigenic strains of *E. coli* in weaned pigs *(39)*. The RPCF culture has shown successful results in decreasing disease caused by *E. coli* in neonatal and weaned pigs. This disease can be fatal and the mortality rate can reach high levels *(40)*. Antibiotics have traditionally been used as a treatment of choice. But over time, *E. coli* have become more resistant to antibiotics and CE is a potential alternative treatment. When developed properly, it could become the method of choice for reducing the disease associated with enterotoxigenic strains of *E. coli*. More work in these and other animal species should be investigated using the CE strategy.

An important area for the use of intervention strategies to reduce pathogens is by using feed additives or treatments. Some of these strategies use heating, pelleting, chemical treatments, or a combination of treatments. The use of chlorate treatment is a very interesting strategy. The reduction of chlorate by nitrate reductase (NR) increases the death rates of *E. coli* and *Salmonella (41)*. *Salmonella* and *E. coli* possess respiratory NR activity *(42)* that can reduce chlorate to cytotoxic chlorite *(43)*, while most gastrointestinal anaerobes lack NR and are not affected *(44)*. Nitrate adaptation in broilers produced a higher reduction of *Salmonella* Typhimurium following chlorate treatment *(45)*. Chlorate treatment via oral gavage of weaned pigs resulted in reduced cecal concentrations of *Salmonella (44)*, and reduced *E. coli* O157:H7 in the pig gut *(46)*. *E. coli* O157:H7 in sheep can also be reduced by chlorate supplementation *(47,48)*. This is an example of a unique chemical treatment that affects pathogens with little or no affect on other gastrointestinal anaerobes and is worthy of further pursuit.

New innovative approaches to successfully develop intervention strategies would be advantageous. Also, educational efforts are needed that focus on the producers of beef, dairy, pork, egg, and poultry describing the best intervention strategies to decrease pathogen contamination on the farm.

5. TARGETING WASTE AT ANIMAL PRODUCTION SITES

Recently there have been some improvements in wastewater discharge to surface waters *(49)*. It is also common to spread large amounts of animal waste on agricultural lands. Prior to spreading the animal waste, there usually is some form of storage. Temperature was targeted as being the single most effective environmental factor affecting pathogen survival in storage *(50)*. Another factor that influences the availability of pathogens in overland flow is their survival in soil. But there is still a lack of basic data on the levels of pathogens found in animal manures *(50)*. Given the diversity of microbial pathogens and the diversity of soil types and geographical locations, it is expected that data gaps still exist. However, future studies should try to integrate as many different parameters as possible into the study design.

The understanding of how microorganisms partition during overland-flow transport is just beginning to emerge. Existing pathogen transport models do not take into account the interactions between the pathogens and the soil and waste particles. Improvements are needed in pathogen transport models *(49)*. Although significant amounts of information on virus and bacterial transport in the subsurface are known, our knowledge of particle-assisted pathogen migration during runoff is still rudimentary. With a better understanding of overland-flow transport of pathogens, better management strategies can be developed and implemented. Solutions to handle the glut of manure should also include both ground-water and surface runoff water protection strategies toward contamination with bacterial load.

Surface runoff and ground-water contamination by pathogens from intense animal production and waste lagoons is an emerging problem. In 2004, it was reported that North Carolina had 4500 active and 1700 inactive swine waste lagoons *(51)*. Because of the problem with overflow and leakage into surface and ground water, North Carolina is no longer permitting waste lagoons *(51)*. The United States is faced with a manure glut because of the large numbers of animals that are produced *(19)*. The amount of manure was estimated in 1997 to be approx 1.36 billion tons *(19)*. Because of public

health and environmental concerns it would be advantageous to develop new technologies to handle large amounts of high nitrogenous wastes that will result in marketable by-products, limit the amount of land required for waste management, limit the impact on surface and ground water, and ultimately also help with global warming.

Until new waste treatment technologies are developed and rigorously tested we should assume that animal wastes harbor harmful pathogens, and their contact with humans and crops should be limited to the extent possible. It is important to thoroughly understand the impact of animal wastes on public health and the environment. The municipal waste industry is currently facing enormous challenges related to the disposal of municipal sewage sludge (biosolids) close to human population centers because of poor management. We must determine the magnitude of the contamination from bacteria found in animal wastes on surface water, ground water, and soil (and the plants that are grown on this soil). To embrace this problem with a better understanding, it will require numerous studies that evaluate the bacteria in animal production facilities, in surface water, and at sites where waste leakage or water runoff is likely.

We only need to remind ourselves of the recent Walkerton, Ontario, tragedy to put in perspective how contamination from cattle manure can cause a large disaster *(52)*. This disaster occurred in a pristine Canadian small farming community, where more than 2300 people became ill and seven people died *(53)*. The tragedy was caused by contamination of a drinking water well by cattle manure containing *E. coli* O157:H7. The potential contamination of water wells should be at the top of the list as a critical focal point for development and implementation of prevention strategies. Another area of concern directly associated with water-well contamination is the use of contaminated water on truck crops. How about the process of recycling this water? What steps are needed to be sure that this water is pathogen-free (including *E. coli* O157:H7) when reused on truck crops?

6. ANTIMICROBIAL RESISTANCE CONSIDERATIONS

Because some antibiotics or classes of antibiotics are used to treat both human and animal illnesses, there is a large debate over the emergence of antibiotic-resistant pathogens. Some health professionals believe that antibiotic-resistant pathogens have emerged because of the therapeutic use of antibiotics to treat animal diseases and by the use of growth promoters in animal feeds *(54–56)*. However, others believe that over-prescription and abuse of antibiotics to treat human illnesses have caused the emergence of antibiotic-resistant pathogens *(57)*. Antimicrobial resistance has become a highly controversial topic in both animal husbandry and clinical medicine. Even though much is known about the role of gene transfer mechanisms in the development of antibiotic resistance, it is extremely important to clearly understand the molecular mechanisms that signal the involvement of horizontal gene transfer of antibiotic resistance genes among bacteria. Once the mechanisms and magnitude of resistance gene transfer are clearly understood and quantified, strategies can be sought to reduce the potential for dissemination of these genes. Also, the role of host signals in the development of antibiotic-resistant bacteria in humans and animals warrants further study.

Research reports have expressed concern that the use of biocides may contribute to the development of antibiotic resistance *(58)*. The use of antimicrobials such as triclosan in hand and dish soaps, deodorant soaps, hand creams, shower gels, surgical scrubs,

facial cleaners, sanitizers, coatings and gloves may very well be the suspect because of the possibility of introducing antimicrobial resistance. It was thought that triclosan was a nonspecific biocide that disrupted cell membranes, thereby leaving the bacteria unable to proliferate *(59)*. However, recent research has shown that triclosan acts at specific targets *(60,61)*. The basis of triclosan's activity is to inhibit fatty-acid biosynthesis *(62)*. Triclosan is a substrate of a multidrug efflux pump in *Pseudomonas aeruginosa*, and triclosan will select for itself as well as for multidrug-resistance in bacteria *(63)*. Therefore, it is quite clear that triclosan should not be in every product possible, as it is now. Especially, it should not be used in surgical scrubs. In the future, chemicals like triclosan should not find their way into consumer products; it is expected that sooner or later triclosan will be removed from the glut of products on the market that now contain it. However, there is a high-dollar commercial investment in using triclosan or chemicals like it in consumer products. This allows the tag of "antibacterial" to be used, which is worth a lot to the companies that manufacture these products.

There has been an ongoing concern whether antibiotic and biocide resistance may be linked in some way *(64–66)*. Indeed a link has been shown *(63,67,68)*. Exposure to antibiotics or triclosan can select for multidrug-resistance by over-expression of identical multidrug efflux systems *(63)*. There is an urgent need for improved surveillance systems to monitor the development of biocide resistance in enteric pathogens. We must be mindful of using biocides in animal production that are also used in food-processing plants, food-preparation facilities, and in human clinical settings. We also must consider stopping the use of biocides like triclosan that show a link between the developments of cross-resistance to antibiotics.

The debate over the origin of antibiotic resistance will ultimately affect the success or failure of global marketplace opportunities. The success of the global marketplace will require truly common sense global food-safety standards and equivalent food-safety systems in place. Sperber stated that industry had responded more quickly on *L. monocytogenes* in 1986 and *E. coli* O157:H7 in 1994 because of the growing alliance between the food industry, trade associations, and research teams *(11)*. He commented, "you put these groups together and it is a powerful alliance" *(11)*. Further, he recommends that for a true global effort to produce food-safety rules that are based on common sense requires the addition and contribution of regulators to the alliance.

We need to be forward looking in terms of antimicrobial resistance considerations. Not only should we be improving detection methods, the understanding of resistance mechanisms, and the types of environmental or human-made pressures that increase resistance, but we need to be putting together the international cooperation needed to swiftly handle an emerging resistance problem anywhere in the world.

7. FOOD-SAFETY STORAGE AND PREPARATION STRATEGIES

A comparison of food-safety knowledge with home food-handling practices found that the level of knowledge of food-safety practices is much higher than the level of in-home application of food-handling practices *(69,70)*. Anderson and coworkers placed cameras in the kitchens of 100 middle-class families to directly observe their food handling and preparation behaviors *(70)*. The researchers evaluated washing hands, cleaning working surfaces and vegetables, modes of cross-contamination, and cooking and chilling behaviors. The results showed the researchers why foodborne illness is such

a problem in American homes. However, in a survey that was conducted by the researchers, nearly all subjects were concerned about food safety *(70)*.

The Council for Agricultural Science and Technology (CAST) discussed consumer education pointing out that the educational goal of increasing the application of safe food-handling and food-consumption practices will continue to target the consumer. However, after much educational effort, the gap between current food-safety education and the ideal remains large *(19)*. Consumers are increasingly aware that foodborne illnesses are a problem, but they continue to blame others and are unaware of the role that they must play in food safety *(19,71)*. McIntosh took a critical look at consumer food-handling behavior *(71)*. He concluded that the consumers are aware of food-safety problems, and yet do not make improvements in their own food-handling behavior *(71)*. McIntosh points out that perhaps an intervention having long-term consequences might be within the public school system, and to potentially use the health education class to introduce and discuss food safety *(71)*. He notes that adolescents are in the process of evolving food habits that will carry over to adulthood *(71)*.

We would like to make further suggestions regarding the use of public school system as a vehicle to embed food-safety strategies into every individual. It is our opinion that during the Junior or Senior year of High School a class be mandatory for every student on food-safety strategies and behavior, and food-safety handling practices for various foods. These handling behaviors should incorporate both a variety of pathogens as well as some common food toxicants. Therefore, the principles of handwashing, surface cleaning, eliminating cross-contamination, cooking, and chilling should all be demonstrated and practiced by the students. The students should also gain knowledge in this food-safety class of the safe ways to store and handle those foods that contain toxicants (e.g., potatoes, celery, parsley, limes, and sweet potatoes).

8. FOOD IRRADIATION

Foodborne illness is preventable. It can be prevented by improved food-production methods, improved food-processing technologies, and improved food preparation and consumption methods within homes. A number of food-processing technologies have been developed and employed in recent years. However, none of the current technologies have had the same level of promise, and unfortunately the level of criticism, as had food irradiation. Ionizing irradiation is one of the most extensively studied food-processing technologies. It was found in 1904 that ionizing radiation could destroy bacteria, and the technology was evaluated in 1921 to destroy trichinae in pork *(72)*. Today, we have nationally and internationally approved irradiation protocols for a variety of food products including uncooked meat and poultry products.

Ionizing radiation is defined as a radiation that has enough energy to remove electrons from atoms thereby leading to the formation of ions. There are different types of ionizing radiation such as X-rays, gamma rays and beta rays (E-beam), depending on the source of the radiation. All types of ionizing radiation function in the same way, i.e., causing ionization of atoms in the food material by stripping off electrons. Over 40 different countries have approved the use of food irradiation. The United States has the most number of approvals for the use of irradiation on foods. However, the United States Food and Drug Administration (FDA) still considers irradiation as a "food additive." The inappropriateness of this classification is evident since other processes such as baking,

frying, and boiling, which also cause chemical changes in the food are not considered as additives *(73)*.

Internationally, foods such as apples, strawberries, bananas, mangoes, onions, potatoes, spices and seasonings, meat, poultry, fish, frog legs, and grains have been irradiated for many years. There is a worldwide standard for food irradiation. The standard was adopted by the Codex Alimentarius Commission, a joint body of the Food and Agricultural Organization (FAO) of the United Nations and the World Health Organization *(73)*. Achieving low doses of irradiation is extremely important to eliminate minor traces of microbial contamination and retain the sensory qualities of specific food items. In conjunction with low-dose irradiation capabilities, dosimeters that can measure such low doses are urgently required. There is a need to develop irradiation protocols for achieving uniform dose distribution on uniquely shaped foods, such as apples, cantaloupes, tomatoes, and heterogeneously shaped packages. Standardized protocols are needed for dosimeter placement and product presentation to the E-beam to achieve minimal min : max ratios for efficient pathogen kill. Studies are also needed to identify the irradiation dose for different food-matrix properties that can eliminate viral pathogens on fruits and vegetables that are minimally processed and are highly vulnerable to fecal contamination *(74)*.

9. NEW AND EMERGING FOOD-SAFETY HAZARDS

During the early 1990s, there was a widespread concern over the possibility of developing resistance in pathogens to antimicrobial agents used in food-animal production. In 1997, a group from Denmark published an exhaustive study on the issue *(75)*. Seyforth and coworkers concluded that although *Salmonella* Typhimurium isolated from animals and humans showed antimicrobial resistance, multiple-resistance was most often acquired outside of Denmark *(75)*. Then Aarestrup and Wegener stated in a review that "There is an urgent need to implement strategies for prudent use of antibiotics in food animal production to prevent further increases in the occurrence of antimicrobial resistance in foodborne human pathogenic bacteria such as *Campylobacter* and *E. coli*" *([76], p. 639)*. However, their concerns immediately became reality. A variant of *Salmonella* Typhimurium strain DT104, resistant to quinolones, was responsible for the death of two people in 1998 *(77)*. This bacterium was traced back to a single Danish swine herd that had been treated with quinolones *(78)*. This episode clearly documents the spread of zoonotic (the transmission of infections under normal conditions from animals to humans) bacteria from animals to humans. The threat of emerging resistant pathogenic bacteria is real. We must be focused with a close watch on the potential for this to happen anywhere in the world *(79)*.

9.1. Bovine Spongiform Encephalopathy Responsiveness and Preparedness

The emergence of bovine spongiform encephalopathy (BSE) is one example of a challenge to the food production safety system upon which the existing food-safety monitoring systems did not have an appreciable impact *(11)*. See a review on risks for human health from animal transmissible spongiform encephalopathies (TSEs) *(80)*. Since BSE is a threat to human and animal health, and fell outside of the existing food-safety health measures, firewalls were developed by the United States to prevent its introduction and amplification *(19)*. Three firewalls have been introduced, briefly: (1) importation of live ruminants and ruminant products are restricted from countries

with BSE cases; (2) the USDA performs immunohistological exams of all brains from cattle condemned for central nervous system disorders; and (3) the FDA has prohibited feeding ruminant meat and bone meal to ruminants *(19)*.

Based on strain typing tests in mice, BSE also causes the human disease, variant Creutzfeldt Jakob disease (vCJD) *(81)*, and both BSE and vCJD had similar incubation times in prion gene replacement studies *(82,83)*. All of the different types of tests used to evaluate the similarities and differences between BSE and vCJD have clearly shown that BSE and vCJD are the same TSE strain *(80)*. While these and other tests for strain-typing showed that chronic wasting disease (CWD) in the family Cervidae, which includes mule deer, white-tailed deer, and Rocky Mountain elk, possesses different patterns from BSE or vCJD. Please see other reviews for further reading concerning CWD *(84,85)*.

Sheep have been given the same food as cattle in some areas, and this may result in the possibility of sheep also contracting BSE. There is a concern of possible transmission of vCJD to humans through BSE-infected sheep, which would be very difficult to distinguish in sheep from scrapie *(80)*. Therefore, methodology to test for BSE in sheep vs scrapie is needed.

Scrapie was recognized in the United States since 1947. It was a speculation that CWD was derived from scrapie. Observations from captive cervids provide evidence of lateral transmission of CWD, which is similar to scrapie, but the details concerning the transmission of CWD still remain to be determined. The CWD agent has been demonstrated to be in various tissues suggesting that the CWD agent may be shed through the alimentary tract, and shedding probably precedes the onset of the clinical disease in both deer and elk *(85)*. However, CWD is like BSE because of the long incubation periods and subtle early clinical signs. There have been no cases reported of human prion disease associated with CWD, whereas human exposure to the BSE agent has resulted in over one hundred deaths due to vCJD *(85)*. The prevalence of CWD has been steadily increasing, and therefore, we need to carefully assess the potential risk that CWD exposure may pose to humans. Recently, the sheep scrapie agent was used to experimentally induce spongiform encephalopathy in elk, and could not be distinguished from CWD of elk *(86)*.

Certainly, much remains to be learned about the transmission and epidemiology of BSE and CWD. Current improvements in CWD testing using enzyme-linked immunosorbent assay (ELISA) technology proved that the ELISA is an excellent rapid test for screening large number of samples and there is a tremendous improvement in CWD detection *(87)*, and similar improvements are needed in the detection of BSE. A much higher proportion of cattle need to be evaluated for BSE. ELISA methods have been developed in collaboration with the French Commissariat à L'Energie Atomique (CEA) for a very highly sensitive and specific ELISA for BSE. This test is available in many countries including the United Kingdom, France, Germany, Belgium, Luxembourg, the Netherlands, Norway, Sweden, Switzerland, Italy, and Spain *(88)*, but not in the United States.

9.2. Is there a Link Between Johne's and Crohn's Diseases?

There are concerns that the cause of Johne's disease in ruminants is also the cause of Crohn's disease in humans *(89,90)*. Johne's disease is a chronic inflammatory

bowel disease of ruminants caused by *Mycobacterium avium* subsp. *paratuberculosis* (MapTb) *(91)*. It is estimated that Johne's disease costs the US dairy industry $200–250 million annually in reduced productivity *(92)*. Crohn's disease is also a chronic inflammatory gastrointestinal disease found in humans that can affect the whole digestive tract, but most commonly affects the lower portion of the small intestine (ileum), where it connects with the large intestine *(93)*. The cause of Crohn's disease is not known *(93)*. It is estimated that almost one million Americans live with Crohn's disease, and that up to 75% of those who live with Crohn's disease may require surgery at some point *(93)*.

Paratuberculosis in ruminants has a prolonged incubation period, resulting in most animals remaining subclinical *(90)*. It is these subclinical animals that can spread the disease to other animals. It is estimated that more than 20% of cow herds in the United States are infected with Johne's disease *(94)*. The survival, in some cases, of MapTb during pasteurization of raw milk *(19,95,96)*, the isolation of MapTb from wildlife, and the similar manifestation of Johne's and Crohn's disease point out why there is a concern. There is a need for more accurate diagnostic testing for MapTb *(90)*. However, the MapTb link between Johne's and Crohn's diseases is highly debated. The debate is primarily based on an inability to satisfy Koch's postulates, since the presence of MapTb has not been demonstrated in all cases of Crohn's disease *(90)*.

The knowledge of the genomic structure of this group of organisms is incomplete, and there is evidence suggesting that *M. avium* and *Map*Tb may represent only two forms of a continuum of complex *M. avium* isolates *(90)*. Recently developed animal models offer the opportunity to study specific interactions between the host/pathogen and potentially lead to improved diagnosis and therapeutic treatment *(90)*. This area would benefit from more researchers evaluating the causes of Crohn's disease, and more pointedly, improved and more accurate diagnostic testing.

10. QUANTITATIVE MICROBIAL FOOD-SAFETY RISK ASSESSMENT

In quantitative microbial risk assessment (QMRA), risk assessment is the first component of the risk analysis process, and it is followed by risk management and risk communication *(97,98)*. Mena and coworkers have discussed QMRA and its application for foodborne pathogens *(98)*. The goal of the risk analysis process is to lead to risk management decisions to better utilize intervention strategies or monitoring procedures. QMRAs are needed to identify the critical points within the food supply system at which additional interventions will have the greatest impact on decreasing the health hazards and improving the overall suitability of foods. Therefore, the result from QMRA can be folded right back into HACCP programs.

The use of QMRA in the food industry has the promise of being very powerful. However, there are many data gaps that must be addressed before QMRA can be fully utilized *(19)*. Also, QMRA is not simple, for it requires microbial modeling. A controversial area is the choice of the model to fit the data with *(98)*. QMRA provides the necessary approach to predict the public health significance of new food production and processing practices, the emergence of foodborne pathogens, and the use of particular critical points for intervention strategies or monitoring procedures *(98)*. With aggressive data gathering along with adoption of models proven to fit real world scenarios, QMRA will become the premier risk assessment tool in the food industry.

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