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INTERVENTION STRATEGIES FOR THE MICROBIOLOGICAL SAFETY OF FOODS OF ANIMAL ORIGIN

TASK FORCE MEMBERS: Michael P. Doyle (Chair), Center for Food Safety, The University of Georgia, Griffin; **Gary R. Acuff**, Department of Animal Science, Texas A&M University, College Station; **Bruce Cords**, Ecolab, Inc., St. Paul, Minnesota; **James Cullor**, Veterinary Medical Teaching and Research Center, University of California–Davis, Tulare; **Jill Hollingsworth**, Food Safety Programs, Food Marketing Institute, Washington, D.C.; **Karen P. Penner**, Food Science Institute, Kansas State University, Manhattan; **Robert A. Seward II**, Regulatory Affairs, American Meat Institute, Arlington, Virginia; **William H. Sperber**, Cargill Corporate Food Safety, Wayzata, Minnesota; **Bruce Tompkin**, Conagra Refrigerated Foods (retired), Downers Grove, Illinois; **REVIEWERS: J. Stan Bailey**, U.S. Department of Agriculture–Agricultural Research Service, Athens, Georgia; **Randall Huffman**, American Meat Institute Foundation, Arlington, Virginia; **John N. Sofos**, Department of Animal Sciences, Colorado State University, Fort Collins; **Lyle P. Vogel**, Scientific Activities Division, American Veterinary Medical Association, Schaumburg, Illinois

INTRODUCTION

The safety of foods of animal origin has become an important concern in the United States for the public, the government, and the food industry. Current intervention strategies need to be examined as they are practiced at the farm, production, processing, and retail levels, and additional strategies need to be identified to decrease further the incidence of foodborne illnesses associated with foods contaminated by animal wastes. Therefore, this paper addresses the issue of the microbiological safety of foods of animal origin during production, processing, and retailing, as well as in food service; describes the role of intervention strategies to prevent, eliminate, or control these hazards; and offers recommendations regarding the development and application of intervention strategies for decreasing human illnesses attributed to foods derived from animals.

The food-retailing business is undergoing dramatic and, at times, revolutionary change. The most significant force behind this revolution is the consumer, who has never had more choices in terms of variety, value, nutrition, convenience, and quality. The "typical" twenty-first century consumer in the United States is difficult to define. The nation's diverse population of more than 281 million consists of a large number of single professionals and two-income families, as well as an increasing number of retiring baby boomers. Additionally, single-income families with "stay-at-home moms" have undergone a small increase, harkening back to the nuclear family of the 1950s and 1960s. Males and females represent almost equal portions of the U.S. population. Although it is a challenge to characterize the typical U.S. family, the food industry seems to be interpreting the demographic landscape successfully by providing a wide variety of food choices; the Food Marketing Institute (FMI) has reported that the median number of items carried in a supermarket is 35,000 (FMI 2001).

In the early 1900s, U.S. shoppers bought almost all food as ingredients or in raw form to be prepared for meals eaten at home. A century later, consumers are buying nearly half their food at restaurants and take-out establishments, a trend boosted largely by growth in fast-food sales. The Bureau of Labor Statistics' Consumer Expenditure Survey (U.S. Department of Labor 2001) indicates that food consumed at home accounted for 58 cents of the total food dollar in

1999. Even though families continue to eat most meals at home, an increasing number of these meals are prepared fully or partly by outside sources. Annual retail and restaurant food sales in the United States approach $800 billion.

The Economic Research Service (ERS) reported that U.S. families spent 10.6% of their disposable income on food in 2000 (USDA–ERS 2001). Another report by the FMI (2003) stated that the average weekly grocery bill ranges from $52 for one person to $138 for households of five or more. According to reports in *Progressive Grocer* (2000) and *Supermarket Business* (2000), in 1999 almost $50 of every $100 spent in grocery stores went to purchase perishables. Of that $50, $15 was used to buy nonfrozen meat, poultry, and fish; more than $3 was spent at the service deli department and more than $9 on dairy products.

When the FMI asked executives in the food service industry what single factor could most affect their business, their number one response was "food safety" (FMI 2000). According to the FMI's "Trends in the United States" (2003), when consumers were questioned about the importance of a variety of factors they considered when food shopping, a clean, neat store ranked first, followed by high-quality fruits and vegetables. In that survey, 79% of shoppers indicated they were completely or mostly confident in the safety of foods in the supermarket. But consumers did believe that food safety problems could occur at various points in the food chain between the farm and their home. When asked where food safety problems were most likely to occur, consumers listed processing/manufacturing plants (35%), restaurants (15%), homes (10%), transportation (8%), grocery stores (6%), all the above (18%), and farms (4%).

In that same survey, 82% of consumers said that bacteria were a serious health risk. When asked what steps they took to keep food safe, the majority (87%) answered that they washed their hands and food-preparation surfaces. Consumers who took food safety actions at home said most often that they did so to stem the spread of harmful microbes.

Thirty years ago, food usually was consumed at home, in meals prepared there from raw foods of animal or plant origin that were purchased at a local grocery store. Fully prepared products with extended shelf life were much less common, and the known foodborne pathogens of concern consisted primarily of those found regularly on raw foods of animal origin (e.g., *Salmonella*) or those that might be of concern after improper handling or temperature abuse (e.g., *Staphylococcus aureus* and *Clostridium perfringens*). The success of extended-shelf life refrigerated foods has led to new concerns with psychrotrophic pathogens—those that grow at refrigeration temperature—such as *Listeria monocytogenes*. Newly recognized pathogens such as *Campylobacter* and *Escherichia coli* O157:H7 also have emerged in foods of animal origin, necessitating a rethinking of traditional safety barriers in food.

The most recently published data from the U.S. Centers for Disease Control and Prevention (CDC) on reported foodborne disease outbreaks for which etiology and transmission vehicle could be identified indicated that foods of animal origin accounted for approximately one-half of the outbreaks (USDHHS–CDC 1996). Most reported outbreaks were of salmonellosis, followed by illnesses caused by pathogenic *Escherichia coli, S. aureus*, and then *C. perfringens*. The most frequently reported vehicles of transmission within foods of animal origin were beef, pork, and eggs, in that order. Through its Emerging Infections Program Foodborne Diseases Active Surveillance Network (FoodNet), the CDC also monitors foodborne disease at nine U.S. sites. In 2002, the incidence of diagnosed infections per 100,000 population was highest for *Salmonella*, followed by *Campylobacter*, *Shigella*, and *E. coli* O157:H7 (USDHHS–CDC 2001a). No designation was made within this data set for vehicle of transmission. Furthermore, these data have limitations because most foodborne disease is not reported and FoodNet data are drawn solely from laboratory-confirmed cases.

Although it has not been listed prominently in previous CDC reports on the incidence of foodborne disease in the United States, *L. monocytogenes* has been implicated in several recent outbreaks and is responsible for high mortality among sporadic cases of illness. Concerns regarding illness caused by this microorganism are limited primarily to ready-to-eat products, including foods with animal origins. Although illnesses caused by *S. aureus* and *C. perfringens* certainly are common, conditions leading to illness are related primarily to inappropriate handling and preparation practices.

Microorganisms are associated regularly with animals to be used for food, and unless processing is applied to provide pasteurization, these microorganisms also will be associated with the resulting raw foods of animal origin. Many microorganisms will cause spoilage, whereas others may be capable of causing foodborne disease if they are not eliminated from or decreased in the product before consumption. Good manufacturing practices (GMPs) to control microbiological contamination are a foundation for producing foods under process control but their on-farm equivalents, good agricultural practices, are less frequently applied.

The Hazard Analysis and Critical Control Point

(HACCP) system is designed to prevent, eliminate, or decrease potential food safety problems during preparation. Enteric pathogens, usually in small numbers, often exist as part of the naturally occurring microflora of raw foods of animal origin, and few opportunities exist for elimination of these foodborne pathogens in processing raw foods that remain freshlike. Application of intervention strategies within production and processing of raw foods of animal origin reflects an attempt to increase the ability of food production systems to control such microbial hazards.

Production Issues

Sources of Pathogenic Contamination of Live Animals

Most foodborne pathogens associated with foods of animal origin are carried in the intestinal tract of livestock or poultry as innocuous microflora and are excreted in their feces, which can contaminate meat during slaughter, milk when squeezed from the cow, and the environment in which the animals live. An exception is *Salmonella* Enteritidis in laying hens in which the bacteria colonize the reproductive tract of hens and are within the egg contents when the egg is laid (Gast, Guard-Petter, and Holt 2002).

Although the magnitude of the concern about transmission of pathogens through contaminated feed to animals is unknown, attempts to decrease the prevalence of pathogens in feed remain a prominent feature of the "Farm-to-Table" approach to food safety. Whereas feedstuffs conceivably could be contaminated with a variety of pathogens, most attention has been focused on the occurrence of *Salmonella*. A U.S. Food and Drug Administration (FDA) survey (McChesney 1995) revealed that 82% of meat and bone meal (MBM) and 37% of vegetable protein (predominantly soybean meal [SBM]) contained salmonellae, but only 16% of completed feeds using these ingredients tested *Salmonella*-positive. Current U.S. prevalence of salmonellae in both MBM and SBM is approximately 25% (APPI 2000). The current prevalence of salmonellae in European Union and Australian feedstuffs is approximately 1% (Sperber, W. H. 2000. Personal communication, unpublished data). Although feed and food are treated identically in the federal Food, Drug, and Cosmetic Act, less attention has been given to the presence of *Salmonella* in animal feed than in food for human consumption.

Water is an obvious potential source of pathogens because it can contain nutrients from feed or manure and be contaminated with pathogens, thereby serving as a vehicle to contaminate or infect animals on consumption. *E. coli* O157:H7 is found commonly in water troughs on farms and feedlots and persists in these environments for as long as 4 months (Hancock et al. 1998). Similarly, open-water systems in poultry houses frequently are contaminated with salmonellae.

Pathogens frequently are transferred from animal to animal, by direct fecal contact on the farm, in feedlots, or during transportation. This is a primary source of pathogen transmission among livestock and poultry.

Pathogens have been found in many animals, including pests such as rodents, mice, birds, and insects. Pests can serve as vectors to contaminate grow-out operations for food animals, although wild birds do not seem to be a major vector for *Campylobacter* transmission in poultry (Stern, N. J. 2001. Personal communication). Flies also have been identified as vectors of foodborne pathogens in livestock and poultry production.

Prevalence of Pathogenic Contamination

Cattle feces is the primary source of *E. coli* O157:H7 (Hancock et al. 1997b, 1998). Whereas most cattle test positive at some time in their life, carriage of this pathogen usually lasts only one or several months. Early studies revealed that in individual cattle the pathogen typically was found at an incidence rate lower than 2% (ranging from 0 to 5%). More recent studies of cattle at slaughter and during the summer months (the peak time of year for carriage of *E. coli* O157:H7) revealed a prevalence rate of 28% (Elder et al. 2000). Feedlots and barns usually are positive for *E. coli* O157:H7 because of the presence of feces.

Crates and transportation vehicles have been shown to be involved in the transmission of *Salmonella* and *Campylobacter* spp. in poultry production (Stern, N. J. 2001. Personal communication). Swine and cattle also have been shown to carry *Salmonella* at rates as high as 64% (Davies et al. 1997; Wells et al. 2001).

There are seasonal and geographical variations in rates of pathogenic contamination. In one study, *E. coli* O157:H7 was found at rates of 2.6% in June and 0% in December (Hancock et al. 1997a). In a study of 3,640 dairy cows, *Salmonella* was detected at rates of 11.2% in the summer and of only 1.9% in the winter (Wells et al. 2001). Similarly, a study of feedlot cattle revealed a *Salmonella* prevalence of 96% in the summer and 60% in the winter (Sperber, W. H. 2001. Personal communication). A nationwide survey of *Salmonella* in dairy cattle revealed a prevalence rate twice as high in the South (63%) as in the rest of the United States (32%) (Wells et al. 2001).

Because of the great numbers of animals produced for food in this country, the United States is faced with a manure glut—an amount estimated at approximately 1.36 billion tons in 1997. Of this total, approximately 1.2 billion tons was cattle manure; the remainder came from hogs (116 million tons), chickens (14 million tons), and turkeys (6 million tons) (U.S. Senate 1998). This quantity equals 5 tons of animal manure produced annually for each person in the United States, an amount 130 times the amount of human waste produced. Because of likely contamination with pathogens, the vast quantity of this manure has public health implications beyond the food supply. It can pollute drinking water and contaminate crops when used raw as fertilizer and when entering irrigation water. In addition to public health concerns, environmental concerns related to odors, emissions, and water pollution with excessive nutrients are receiving increased public attention.

Mechanisms of Carriage and Transmission of Human Pathogens by Animals

Human illnesses associated with foods of animal origin are caused largely by fecal contamination of raw animal food by bacteria such as *Salmonella*, *Campylobacter*, and *E. coli* O157:H7. In contrast, listeriosis results primarily from consumption of certain animal products cross-contaminated with *L. monocytogenes* from the processing plant environment.

The 1994 regulatory declaration of *E. coli* O157:H7 as an adulterant in raw ground beef and more recently in non-intact food products has not decreased substantially the incidence of *E. coli* O157:H7 infection in humans from 1996 to 2002 (USDHHS–CDC 1998a,b, 1999, 2000, 2001a, 2003). FoodNet data for the incidence of *E. coli* O157:H7 infections in the United States has ranged from 2.1 to 2.8 cases per 100,000 population between 1996 and 2000 for 5 sentinel sites, and from 1.6 to 2.0 cases per 100,000 between 2000 and 2002 for 9 sentinel sites (Table 1). *E. coli* O157:H7 contamination occurs throughout the production and processing chain, with contamination prevalences of 11–28% of cattle feces (Elder et al. 2000), 11% of hides, 3–28% of carcasses (Elder et al. 2000), and up to 0.8% of retail raw ground beef (USDA–FSIS 2003b). Despite intense surveillance of meat processors by the USDA Food Safety and Inspection Service (FSIS), the number of laboratory-confirmed human illnesses caused by *E. coli* O157:H7 (1.7 cases per 100,000 population in 2002) (USDHHS–CDC 2003) continues at unacceptable levels in part because many other vehicles besides ground beef are important modes of transmission (Kennedy et al. 2002). These modes include direct contact with contaminated cattle hides and feces, exposure to contaminated drinking and recreational water, and consumption of foods exposed to cattle manure.

Certain food animals can serve as vectors for the transmission of parasitic diseases to humans. Swine can be involved in the transmission of trichinosis and toxoplasmosis, and beef cattle can transmit tapeworm diseases. Cattle also are considered an indirect vector for the transmission of cryptosporidiosis, which may result when infected feces contaminate drinking water supplies.

Influence of Production Practices on Prevalence of Foodborne Pathogens in Animals

The type of production operation, such as free-range or confined, may be a significant factor affecting the incidence of human pathogens in animals. The herding instinct, common in many species, cannot be managed in free-range situations; animals therefore are exposed to concentrated fecal matter that may contain human pathogens. Studies revealed that organic broiler flocks and free-range chickens were more likely to be contaminated with *Campylobacter* than conventional broilers raised in

Table 1. Incidence of *Escherichia coli* O157:H7 infections based on 5 original FoodNet sites in 5 U.S. states (USDHHS–CDC 1998a, b, 1999, 2000, 2001a, 2003)

Year	CA	CT	GA	MN	OR	Overall Incidence
	(No. of cases per 100,000)					
1996	1.1	2.3	0.5	5.2	2.3	2.7
1997	0.9	1.4	0.2	4.2	2.5	2.3
1998	NDR[a]	NDR	NDR	NDR	NDR	2.8
1999	NDR	NDR	0.6	NDR	NDR	2.1
2000	NDR	NDR	0.5	4.4	NDR	2.7 (2.0)[b]
2001	1.1	1.1	0.6	4.8	2.3	(1.6)[b]
2002	1.0	1.4	0.7	3.6	5.1	(1.7)[b]

[a]NDR, no data reported
[b]9 sites

confined housing; for example, 100% of organic broiler flocks were *Campylobacter* spp.-positive compared with 36.7% of conventional broiler flocks (Heuer et al. 2001; Treisierra-Ayala et al. 1995). The 1995 National Animal Health Monitoring System swine report indicated a greater prevalence of *Salmonella* in larger herds: 51% if more than 10,000 head; 32% if less than 2,000 head (USDA–APHIS 1995). Additional factors known to influence pathogen prevalence are season and animal age.

The significance of antibiotic-resistant pathogens is the subject of an energetic debate because some of the same antibiotics are being used to treat human and animal illnesses. Certain public health professionals believe that antibiotic-resistant pathogens have emerged largely because of the therapeutic use of antibiotics to treat animal diseases and because of the use of antibiotics as growth promoters in animal feeds (Kelley et al. 1998; Rajashekara et al. 2000); others believe that antibiotic-resistant pathogens have emerged primarily because of the extensive overprescription and abuse of antibiotics to treat human illnesses (Price 2000). All these factors likely are significant contributors to the development of antibiotic-resistant pathogens.

Antibiotics are added to feed because they enable the production of healthier animals that grow faster (NRC 1999). An estimated 25 to 50% of all antibiotics used in the United States are used in animal production (Yates, D. A. 2002. Personal communication; NRC 1999). The use of antibiotics results in improved feed efficiency, growth, and animal health (Franco, Webb, and Taylor 1990). But the effectiveness of antibiotics to treat human illnesses is decreased as pathogens develop resistance. Efforts are increasing worldwide, therefore, to prohibit the use in animals of those antibiotics—particularly analogues of vancomycin, virginiamycin, and newer forms of those antibiotics—that retain efficacy against the multiple-antibiotic-resistant microorganisms already present in the human population.

Intervention Strategies at Production and Slaughter

Quantitative microbial risk assessment (QMRA) is a structured process for determining the risk associated with a microbiological hazard in a food. Such risk assessments provide structured information that can enable the identification of intervention strategies not only at production, but throughout the food continuum, that should effect the greatest improvements to public health. Unfortunately, QMRA is still in its infancy, having many critical data gaps that must be addressed before it can be adopted and applied routinely in identifying points of intervention and intervention strategies having the most impact. Once the essential data are obtained, however, QMRA can be used as a powerful tool to assist decision makers in identifying the best options for interventions from production to consumption.

A number of production and slaughter methods and intervention practices that have potential to decrease the presence of pathogens on fresh meat and poultry and on eggs are summarized in Table 2.

Feed Additives and Treatments

Certain chemical additives and heat treatments can decrease or eliminate pathogens in feed. It has long been known that pelletizing of feed is an effective pathogen-control step if the pelletizing temperature exceeds 80ºC (Himathongkham, Pereira, and Riemann 1996). In one study of MBM, 39 of 63 samples (approximately 62%) were *Salmonella*-positive before pelletizing, but only 1 sample of 51 samples (approximately 2%) was positive after pelletizing (Cox et al. 1986).

Competitive Exclusion

According to the proven “Nurmi” concept introduced in Finland, beneficial microorganisms can be used to prevent or decrease intestinal colonization by pathogens (Nurmi and Rantala 1973). This strategy, known as *competitive exclusion*, is defined as the use of microbial cultures to outcompete harmful pathogens (Buchanan and Doyle 1997). A mixture of 29 nonpathogenic bacteria isolated from healthy adult chickens decreased the prevalence of *Salmonella* from 7% in untreated chicks to 0% in treated chicks (Hume et al. 1996; Martin et al. 2000; Nisbit, Corrier, and DeLoach 1997; USDA–ARS 1998). An undefined culture that also is effective in greatly decreasing the prevalence of *Salmonella* in poultry has been developed for this use (Bailey, Cason, and Cox 1998; Blankenship et al. 1993). Zhao and colleagues (1998) demonstrated that certain isolates of *E. coli* are antagonistic to the growth of *E. coli* O157:H7 in cattle. When treated with the beneficial *E. coli*, the cattle rumen, colon, and feces of most animals were cleared of *E. coli* O157:H7 within 12 days, in contrast to the more than 33 days that *E. coli* O157:H7 persisted in controls. *Lactobacillus* spp. also have been identified as a beneficial competitive exclusion treatment to reduce *E. coli* O157:H7 in cattle (Brashers, Jaroni, and Trimble 2003).

When health claims or pathogen-reduction claims are made for competitive exclusion products, those products are regulated by the FDA as drugs, which typically require many years for approval; this practice can diminish the possibility of their commercial use significantly.

Bacteriophages and Vaccines

These agents are used because they either can kill pathogens directly or can prevent their colonization of animals. Calves treated with bacteriophages were cleared of fecal shedding of *E. coli* O157:H7 in a shorter time than were untreated controls (Waddell et al. 2002). Because of peculiarities within the ruminant digestive system, traditional vaccination procedures are unlikely to control pathogens in cattle; several different approaches, therefore, are being evaluated. One approach is the targeting of specific genes in pathogens. Another is the development of vaccines for the specific proteins involved in attachment of the pathogen to the host's intestinal lining. Research is under way to develop a vaccine for the control of *E. coli* O157:H7 in cattle. A vaccine has been applied successfully in the United Kingdom to decrease *S.* Enteritidis infection of layer chickens.

Husbandry Practices

Drinking water is a significant vehicle for the infection of animals (Hancock et al. 1998; Hoover et al. 1997; LeJeune, Hancock, and Besser 1997; Limawongpranee et al. 1999; Morgan-Jones 1982; Renwick et al. 1992; Rice and Johnson 2000; Sargeant et al. 2000; Shere, Bartlett, and Kaspar 1998). In this low-nutrient environment, it is likely that *E. coli* O157:H7 and, perhaps, other pathogens are present in biofilms especially resistant to antimicrobial treatment.

Feed withdrawal or diet alteration may affect the incidence of pathogens as well as the speed of elimination of pathogens from animals before slaughter (Garber et al. 1999). This effect may be associated with the rumen's marked acidification, which occurs with high-grain diets. Litter of high moisture content and high water activity is of particular concern for disseminating pathogens among poultry (Hayes et al. 2000).

Many human infections with *E. coli* O157:H7 occur in rural areas. These occur among farm workers, visitors to farms, and children visiting fairs and petting zoos, largely as a result of contact with contaminated cattle manure (Dawson et al. 1995; USDHHS–CDC 2001b).

Slaughter Practices

Animals presented for slaughter usually are dirty and harbor pathogens from fecal contact in pastures, grow-out houses, feedlots, and transportation vehicles. A variety of successful strategies are being used to address this issue (See Table 2).

Firewalls to Prevent a Bovine Spongiform Encephalopathy Outbreak

The emergence of bovine spongiform encephalopathy (BSE) has presented a new threat to human and animal health. Three firewalls have been established in the United States to prevent the introduction and subsequent amplification of BSE in the United States: (1) since 1989, importation of live ruminant animals and ruminant products from countries with native cases has been restricted; (2) since 1990, the USDA has performed immunohistological examinations of all brains from cattle condemned for central nervous system disorders; and (3) in 1997, the FDA enacted a feed ban prohibiting the feeding of ruminant MBM to ruminants. In 2001, the FDA admitted that its 1997 ruminant feed ban for BSE control had been enforced laxly but that, subsequently, enforcement of this rule has become more stringent. Compliance to the ruminant feed ban was over 99% in 2002. In 2003, more than 19,000 high-risk cattle in the United States were assayed for BSE and none was positive. As of April 30, 2003, more than 48,000 high-risk cattle had been tested for BSE in the United States, with none positive. In May 2003, a confirmed case of BSE was detected in a 6-year (yr)-old Canadian beef cow, which was the first identification of BSE in a native North American bovine animal.

Milk and Dairy Production

Although dairy animals can carry a wide variety of pathogens that also are of human health concern, pasteurized milk and dairy products have an excellent food safety record. The main reason for this is the Pasteurized Milk Ordinance, which specifies pasteurization requirements for dairy products. No outbreaks of foodborne illness have been associated with properly pasteurized and packaged dairy products in the United States. There are, however, certain recent concerns related to an association between Johne's disease in cattle and Crohn's disease in humans and the fact that in rare instances *Mycobacterium avium* subsp. *paratuberculosis* may survive pasteurization (CAST 2001). On rare occasions, postpasteurization contamination of milk or dairy products has been associated with foodborne illness.

Food Processing Issues for Manufactured Foods

Ready-to-Cook Foods of Animal Origin

Meat and Poultry

Significant changes have occurred in the conditions for converting live animals to ready-to-cook foods. Two

Table 2. Examples of food safety intervention strategies applied or proposed at production and slaughter

Methods	Pathogens Affected	Reference Sources
Feed additives and treatments		
• Mixture of ammonium formate/ ammonium propionate/sodium sorbate	*Salmonella,* especially in liquid feeds	
• Sodium chlorate	• *Escherichia coli* O157:H7 • *Salmonella typhimurium* DT104	Anderson et al. 2000
• Propionic acid combined with heating	• *Escherichia coli* O157:H7 • *Salmonella typhimurium* DT104	Matlho et al. 1997
• Pelletizing	*Salmonella*	Cox et al. 1986; Himathongkham, Pereira, and Riemann 1996
• Heating	*Salmonella*	Himathongkham, Pereira, and Riemann 1996
Competitive exclusion		
• PREEMPT, mixture of 29 nonpathogenic bacteria from healthy adult chickens	*Salmonella* in chicks	Hume et al. 1996; Martin et al. 2000; Nisbit, Corrier, and DeLoach 1997; USDA–ARS 1998
• Certain isolates of *Escherichia coli*	*Escherichia coli* O157:H7 in cattle	Zhao et al. 1998
Bacteriophages	*Escherichia coli* O157:H7 in calves	Waddell et al. 2002
Husbandry practices		
• Cleaning/disinfecting water troughs, drinking apparatuses	Various	LeJeune, Hancock, and Besser 1997
• Acidification of water to pH 3.5 with organic acids or by chlorination	Various	Byrd et al. 2001
• Sodium chlorate in water before slaughter	Various	Anderson et al. 2000
• Antimicrobial treatments of egg surface to diminish contamination of chicks during pipping	Various	Bailey et al. 1996
• Finishing diet of grain for cattle to diminish fecal shedding time	*Escherichia coli* O157:H7	Garber et al. 1999
• Adjusted litter pH/decreased water activity/ added antimicrobial agents/use poultry houses in rotation	• *Salmonella* • *Campylobacter*	Jeffrey et al. 1998
Slaughter practices		
• Careful process to cut and remove hides/ to contain digestive tract contents/to eviscerate and to split carcasses (beef)	Various	
• Trimming by knife/spray washing with hot water/ pasteurizing with steam/sanitizing with organic acid sprays/vacuum treating with steam (beef)	Various	Bacon et al. 2000; Byrne et al. 2000; Castillo et al. 1998; Dorsa 1997; Dorsa et al. 1996; Nutsch et al. 1998; Sofos and Smith 1998; Sofos, Belk, and Smith 1999
• Removing exterior contaminants in counterflow scalders and defeathering machines (poultry)	Various	
• Antimicrobial carcass sprays and chill-tank water treatments	Various	

major changes are (1) control of the process to decrease the likelihood of contamination during slaughter and (2) implementation of procedures to decontaminate carcasses early and/or at the end of the process. Two factors have brought about these changes in slaughtering procedures since the mid-1990s.

The first factor has been implementation of the concept of "zero tolerance" for fecal contamination (USDA–FSIS 1995, 1997a,b), a concept in which tiny brown, yellow, or green spots containing fibrous or plant-like textures on carcasses are considered fecal material. As a result, when it is determined that poultry carcasses contain fecal material after chilling, it is assumed that the chill water is contaminated. Chill water therefore is emptied and the equipment cleaned, thereby stopping production. For beef, pork, and lamb carcasses, material is trimmed by knife, or steam-vacuuming if the visible feces is less than 1 inch in diameter, before final wash and placement in coolers. Certain beef operations have been closed temporarily when inspectors found material they deemed fecal on a few carcasses in coolers. The zero tolerance policy for fecal material has been implemented rigorously by the inspection agency, to such a degree that the source and the composition of minuscule matter often are uncertain. Despite its controversial aspects, the zero-tolerance policy has decreased the presence of visible fecal matter on carcasses.

The second factor causing changes in slaughtering procedures has been the adoption of performance standards for salmonellae on carcasses and in raw ground meat and poultry (USDA–FSIS 1996). These standards move the measure for control of potential enteric pathogenic contamination from the visible (fecal matter) to the invisible (salmonellae). The standards were derived from national baseline studies for each commodity, and considerable debate continues over the validity of these performance standards. Even so, the standards have led to improved management of the slaughtering process and to decreased prevalence of salmonellae on fresh meat and poultry (Table 3).

Salmonella performance standards have led many companies to reevaluate their processes so as to determine where contamination may occur and to make further adjustments to decrease its likelihood. Additionally, millions of dollars have been spent on systems to decontaminate carcasses after slaughter. The choice of system is species specific. For example, use of inside-outside bird washers before carcasses enter final wash and chill tanks has increased throughout the poultry industry. Most plants have incorporated bactericidal sprays on carcasses before or after chill. Improvements in pH control during chlorination of chill tank water seem to make chilling a more reliable decontamination step. Before being placed in the cooler, most beef carcasses now pass through a decontamination step consisting of hot-water wash or steam. Certain processors also apply organic acid (e.g., lactic acid sprays) or other chemical treatments at selected points or after application of hot water or steam.

Systems for preventing contamination of beef carcasses and for decontaminating them generally involve multiple interventions during slaughtering, eviscerating, dressing, and chilling. The choice of control measures is based on the cost of each action, appropriateness to the facility (e.g., space limitations), and results of research demonstrating efficacy of the control measure on decreasing pathogen contamination (Bacon et al. 2000; Byrne et al. 2000; Castillo et al. 1998; Dorsa 1997; Dorsa et al. 1996; Nutsch et al. 1998; Sofos and Smith 1998; Sofos, Belk, and Smith 1999).

It is uncertain whether more effective procedures can be developed either to further decrease the likelihood of contamination or to improve the final decontamination. A limiting factor influencing future development of pathogen-control measures relates to denaturation or undesirable changes of carcass surfaces. There are two hurdles: the regulatory view that fresh meat and poultry must not have a cooked appearance, and the unwillingness of customers and consumers to accept a degree of surface denaturation. If these deterrents can be overcome, then additional decreases in contamination may result.

Table 3. Prevalence of *Salmonella* from the USDA–FSIS verification testing program for all Set A samples for the years 1998 through 2002 (USDA–FSIS 2003a)

Product	Performance Standard Baseline %	No. Samples	% Positive
Broilers	20.0	40,622	10.9
Market hogs	8.7	24,052	4.7
Cows/bulls	2.7	10,285	2.0
Steers/heifers	1.0	8,355	0.4
Ground beef	7.5	105,691	3.2
Ground chicken	44.6	1,426	19.8
Ground turkey	49.9	4,787	26.6

Perhaps hot water or steam also can be applied in poultry production, where, to date, heat applications have been used infrequently. A common decontamination practice involves application of combinations of treatments (e.g., heat, organic acids, and other antimicrobial agents) to enhance microbial destruction on carcasses.

It is assumed that decreases in the prevalence of salmonellae on carcasses will lead to decreases in other enteric pathogens (e.g., *Campylobacter* on poultry, *E. coli* O157:H7 on beef), but this assumption has yet to be proved and remains questionable. It seems that the control measures adopted have decreased *Salmonella* contamination on beef carcasses but the prevalence of *E. coli* O157:H7 in ground beef did not change until 2003 (Table 4). This relation, however, is difficult to assess because the USDA–FSIS increased the size of its sample and the sensitivity of its monitoring procedures for *E. coli* O157:H7 in ground beef while the industry was implementing new contamination control procedures for carcasses.

After slaughter, carcasses are chilled to temperatures preventing growth of most enteric pathogens. Subsequent processing normally occurs in refrigerated rooms. Considering the relatively slow rate at which salmonellae and *E. coli* O157:H7 can multiply at 10°C and below (*Campylobacter* cannot grow below approximately 30°C), substantive growth would not be expected during the commercial conditions that normally exist for storing and distributing raw meat and poultry (ICMSF 1996).

Carcasses are subjected to a wide variety of processing procedures in the production of ready-to-cook products. Procedures can involve cutting into smaller portions, trimming, grinding, injecting, marinating, salting, and adding cure and/or spices. Products may be packaged in many different forms and may be distributed either frozen or refrigerated. No procedure, however, can be relied on to decrease enteric pathogens on raw meat and poultry products. Thus, a technological void exists in the stage between carcass chilling and purchasing for cooking.

Irradiation is a process that could be used to inactivate pathogens in consumer-packaged raw meat and poultry products. This process has been applied to raw poultry on a very limited scale for several years. Use of irradiation for ground beef has been increasing, but the percentage of product being irradiated remains small at this time. There are several hurdles to the increased use of irradiation of ready-to-cook products: consumer acceptance of irradiation-treated food, increased price of food to cover the cost of irradiation, and irradiation's negative effect on odor and flavor of the treated product (e.g., using pasteurization doses to irradiate meat containing more than 10% fat may result in products with unacceptable sensory qualities) (Lefebvre et al. 1994). In addition, unlike other food processes, irradiation is regulated as a food additive. The slow food additive approval process has greatly limited the application of irradiation. Labeling requirements for irradiated foods tend to diminish consumer acceptance of the process, further limiting its applications.

Unpublished research (Kostides, E. 1999. Personal communication) has demonstrated that sodium diacetate can prevent multiplication of salmonellae and *E. coli* O157:H7 in ground beef in the event of holding at temperatures permitting pathogen growth. Use of this additive should decrease the importance of one of the significant risk factors—temperature abuse of beef before grinding— identified during the Canadian risk assessment of ground beef (Cassin et al. 1998). An ideal additive would prevent growth during temperature abuse and render pathogens more sensitive to heat so that they die more rapidly during "undercooking." Acidified calcium sulfate (Safe$_2$O®) can accomplish the latter (Doyle, M. P. 2003. Personal communication). Use of additives for this

Table 4. Prevalence of *Escherichia coli* O157:H7 in ground beef (USDA–FSIS 2003b)

Fiscal Year	No. Samples	No. Positive	% Positive
1995[a]	5,291	3	0.057
1996[a]	5,326	4	0.075
1997[a]	5,919	2	0.034
1998[b]	7,529	14	0.19
1999[b]	8,710	29	0.33
2000[c]	6,374	55	0.86
2001[c]	7,009	59	0.84
2002[c]	7,026	55	0.78
2003 (through Nov. 4)	~5,103	18	0.35

[a]25-g analytical samples.
[b]325-g analytical samples.
[c]325-g samples and improved isolation method (i.e., immunomagnetic beads to concentrate cells).

purpose, however, will require a change in U.S. regulations such that certain additives in ground beef will be permitted. This is a legal restriction that may limit such applications.

With the issuance of the HACCP/Pathogen Reduction Regulation, it was estimated that one-half the cost of foodborne illnesses attributed to meat and poultry products was due to *Toxoplasma gondii* (USDA–FSIS 1996). Despite the estimated cost of $2.7 billion/yr in economic loss attributed to meat- and poultry-associated diseases, the regulation did not include directives to control this pathogen. Limited attention has been paid to toxoplasmosis, although one approach suggested for controlling this disease is to develop a vaccine for cats, which are a reservoir of *T. gondii.*

Eggs

Investigation of the factors influencing the presence of *S.* Enteritidis in eggs has been intensive (FAO/WHO 2002; USDA–FSIS 1998a). Although review of pasteurization requirements for liquid egg products also has been intensive, little or no recent evidence exists that these products have been implicated in illness. The primary source of *S.* Enteritidis infection in the United States has been shell eggs containing *S.* Enteritidis resulting from transovarian infection through colonization of ovarian tissue. Two recent risk assessments provide current information on salmonellae in eggs (FAO/WHO 2002; USDA–FSIS 1998c).

During the past several years, the number of instances of salmonellosis in the United States due to *S.* Enteritidis in eggs has been decreasing. Rates of illness from *S.* Enteritidis declined 48% from 1996 to 1999, and declined 7% from 1998 to 1999 (USDHHS–CDC 2000). The incidence rate declined from 2.5 to 1.8 per 100,000 population between 1996 and 2000, respectively (USDHHS–CDC 2001a). This decrease reflects implementation of the results of a massive research effort that identified a combination of improved farm-management practices for decreasing *S.* Enteritidis contamination of flocks, a system for detecting *S.* Enteritidis-positive flocks, and diversion of eggs from infected flocks to pasteurization. Surprisingly, the substantial decline in estimated incidence of *S.* Enteritidis infections before 1999 largely has been reversed by an increase in infection more recently (USDHHS-CDC 2003). It seems that renewed emphasis on intervention strategies, both on the farm and elsewhere in the egg production-to-consumption continuum, is needed to address this situation.

Additional approaches in the United States to decrease *S.* Enteritidis infections among consumers of shell eggs are to promote timely collection of eggs on the farm, control of egg temperature during storage (USDA–FSIS 1999) and at retail, and consumer education through safe-handling labels on egg cartons. In the United Kingdom, a significant decrease in *S.* Enteritidis infections among consumers of eggs has resulted from vaccination of the egg-laying flocks, but this promising intervention has yet to be applied in the United States.

Research has led to at least two methods of in-shell pasteurization of shell eggs (Mermelstein 2001). Both methods involve a hot-water immersion process that controls the temperature and time to give a 100,000-fold reduction of *Salmonella* while maintaining the desirable characteristics of the egg. This technology shows promise as an additional means of eradicating *S.* Enteritidis from shell eggs intended for use in food service and for retail sale.

Milk

Although raw milk can contain a variety of human pathogens, it continues to be produced and consumed legally in certain areas of the United States. The interventions available to minimize pathogen contamination consist of managing the health of dairy herds and of applying hygienic practices during milking, storing, and distributing. Although pathogen-free raw milk cannot be ensured, there is no interest at this time in developing new or more effective interventions for enhancing the safety of raw milk because the vast majority of raw milk is subjected to pasteurization or to certain other treatments rendering the product safe for consumers. Consumers are advised not to drink raw milk or consume dairy products made with raw milk.

Ready-to-Eat Foods of Animal Origin

Meat and Poultry

With the exception of *L. monocytogenes*, which is largely an in-plant, postprocessing contamination problem, microbial pathogens potentially associated with ready-to-eat meat and poultry products can be controlled by existing regulatory policies. Accordingly, these products are subjected to a kill step that eliminates pathogens such as *Salmonella*, *E. coli* O157:H7, *Campylobacter jejuni, Yersinia enterocolitica, Trichinella spiralis*, and *T. gondii*. These products have been implicated only rarely in outbreaks of salmonellosis since circa 1981, when changes were made in USDA regulations; these changes were based on research establishing time-temperature treatments that kill salmonellae in cooked beef (Goodfellow and Brown 1978; USDHHS–CDC 1981). An outbreak associated with *E. coli* O157:H7 in fermented sausage in the western United States in late 1994 resulted in changes in the requirements for producing fermented meat products. Current technology is, therefore, usually adequate to control the vegetative pathogens that may be of concern in ready-to-eat meat and poultry products.

The exception, *L. monocytogenes*, continues to be detected on ready-to-eat products, although not because of the bacterium's survival during processing, but rather because of recontamination that occurs during processing. The recontamination rate, according to USDA–FSIS monitoring data, is in the range of approximately 1 to 4% of sample sets analyzed (Levine et al. 2001). Listeriae are introduced frequently into the food-processing environment and can become established as a member of the resident microbial population. Current intervention strategies involve (1) control measures that minimize the bacterium's establishment in equipment (Tompkin 2000; Tompkin et al. 1992, 1999) and (2) efforts to minimize the bacterium's ability to transfer from a nonproduct contact surface to a location where it can contaminate products. Although these procedures can be quite effective, they require continual review and frequent assessment through microbiological monitoring programs.

Improved interventions for control of *L. monocytogenes* could involve improved equipment design for cleanability, maintenance, and reliability. In addition, creation of more effective, affordable sanitizers is needed to prevent *L. monocytogenes* contamination of floors and drains where biofilm formation can occur.

Other interventions consist of (1) using additives to control bacterial multiplication in the product and (2) postpackaging pasteurization. Research has shown that certain additives, especially those used in combination such as sodium or potassium lactate and sodium diacetate, can be quite effective in delaying and slowing *L. monocytogenes* growth. Control of *Listeria* is especially important in foods with a long shelf life that supports *Listeria* growth to large populations. Certain additives currently are being used in commercial products, but a wider selection of approved additives would be desirable. This field of research should continue to be of interest because the risk of human listeriosis is greatest when a large number of cells are consumed by unusually susceptible individuals.

There is considerable interest in postpackaging treatments designed to eliminate *L. monocytogenes* that, between cooking and packaging stages, may have contaminated the products. Systems based on placing the packaged product into hot water have been developed and have been used commercially for more than 10 yr. Improved equipment and technology, however, are needed to decrease costs and damage to packaging materials and products. Hydrostatic high-pressure technologies also can be effective, but they are costly, require a large amount of space, and are limited to batch processing for packaged products as well as to specific quantities of product. Despite these drawbacks, high pressure generally does not alter the sensory properties of the product or have an unacceptable effect on the package and likely will be applied in certain situations.

Irradiation should eliminate *L. monocytogenes* in packaged products, but the effect on odor and flavor may be a concern. There are so many types of ready-to-eat meat and poultry products that a variety of intervention technologies are needed to address the *L. monocytogenes* issue. There seems to be no single solution to eliminating pathogen contamination from all products. The preferred technology likely will be influenced by consumer acceptance, cost, space requirements, effect on product, intended market, and preparation method.

Eggs

Commercially processed eggs are used primarily as ingredients in other foods. During the 1960s and 1970s within the egg-processing industry, major changes occurred as a result of concerns about *Salmonella*. During this period, regulations were adopted that required pasteurization. Improved technology was necessary to pasteurize the various types of liquid egg products (e.g., liquid whole eggs, albumen, salted egg products) and to produce dried egg products that would test negative for salmonellae without losing functionality and other quality attributes. The recent history of these products has been favorable, and they have not been associated with outbreaks of salmonellosis.

Milk

In addition to being processed for drinking, milk is used in the manufacture of a variety of dairy products including ice cream, yogurt, cottage cheese, butter, natural and processed cheeses, nonfat dry milk, and condensed milk and is an ingredient in bakery and other food products. Microbiological challenges consist primarily of the survival of *Salmonella* in aged natural cheeses and the growth of *L. monocytogenes* in fluid milk and certain soft cheeses. The potential for survival of salmonellae in natural cheese has been investigated extensively and reviewed (Johnson, Nelson, and Johnson 1990a, b, c), but a more current review of this information is needed. Outbreaks of salmonellosis are rarely associated with natural cheeses.

Listeriosis has been associated with the consumption of fluid milk and certain types of soft cheeses when growth has occurred before consumption. Strategies for controlling this risk consist of preventing contamination after pasteurization of milk and during manufacture of cheese and using pasteurized milk in cheese production. As with ready-to-eat meat and poultry products, environments must be controlled to decrease the likelihood of product contamination.

Retail Food Markets

The U.S. retail food industry emphasizes four main target areas when developing food safety controls: food sources, retail operations, retail employees, and consumer education. Supermarkets have structured food safety initiatives to reflect the risk factors of their industry. Assessments by industry and the FDA have identified those practices and behaviors affecting food safety that need the most attention (USDHHS–CFSAN 2000). These are control of time and temperature, proper sanitation of food-contact items, prevention of cross-contamination, and personal hygiene of food handlers.

The retail food industry faces unique hurdles in its efforts to achieve food safety. Employee turnover rate can be extremely high, and retailers have had difficulty in retaining properly trained employees to perform key food safety-related tasks.

Few, if any, means exist to make food "more safe" once it reaches the supermarket. For most products, with the exception of foods that are cooked at the supermarket, the retailer cannot eliminate, decrease, or prevent pathogenic contamination that has already occurred. Thus, the primary role of retailers is to control bacterial levels and to minimize cross-contamination.

A shift in the retail food industry has occurred toward handling and preparing potentially hazardous ready-to-eat foods at the store level, such as in-store delis. Critical control points and additional management and monitoring steps now exist in an environment where, previously, good retail practices (GRPs) were sufficient to maintain food safety. Moreover, composition and packaging of products are complex, and retailers are challenged to keep pace with rapidly changing product profiles.

Existing Intervention Strategies at Retail

Despite the challenges, the retail industry has implemented and maintained key food safety practices and intervention strategies. Textbox 1 summarizes existing intervention strategies, showing methods and limitations in five main categories of food retailing: (1) control of sources and suppliers, (2) temperature-monitoring practices, (3) best practices and standard operating procedures, (4) training programs, and (5) consumer education.

New Intervention Strategies at Retail

Technology designed specifically to meet the unique food safety challenges presented at the retail level is still emerging. Equipment and tools being used by retailers have, for the most part, been designed for other purposes. For instance, few thermocouples being used to monitor cooking steps have been altered significantly from their laboratory versions. Technology providers must interact with individuals in the retail industry to design equipment and systems directly applicable to retailers' routine tasks.

Technology applications are needed to address the entire food chain. Currently, a product travels from grower/producer to retailer, bringing with it an incomplete picture of conditions to which it has been exposed. Yet the technology exists to create a system for monitoring product conditions from producer through distributor to retailer, and even to consumer.

Without knowing the costs/benefits, retailers are understandably hesitant to adopt new food safety technologies. Many technologies are offered that look and sound good, but retailers need to know that promised food safety improvements will measurably benefit consumers. New technologies must be scaled to fit the retail environment in which time is short, employee turnover is high, sophisticated technicians are largely absent, and customer service is top priority.

Textbox 2 summarizes methods and limitations for new intervention strategies, considered in six categories: (1) sources and suppliers; (2) hand-held temperature-monitoring devices with data-storage capability; (3) automated temperature-monitoring devices; (4) time-temperature indicators (TTIs); (5) rapid tests for monitoring food safety-related conditions; and (6) product rinses, chemical sanitation systems, and product shelf life extenders.

Food Service

When intervention strategies are being designed to enhance food safety in food service, it is important to remember the breadth of food service organizations—from commercial establishments such as restaurants, taverns, and food carts to noncommercial venues such as schools, hospitals, and prisons (Seward 2000). The food service industry ranges in operations from one-unit stores to international chains with more than 25,000 units. Challenges to such organizations include applying food safety controls uniformly across all sectors of the industry, maintaining minimal standards, and pursuing risk reduc-

Textbox 1. Existing food safety intervention strategies commonly used in food retailing

Methods	Limitations
Control of Sources and Suppliers	
• Safety standards for suppliers • Basic food safety vendor-qualification checklists • Sophisticated or tailored specifications including microbiological testing • Supplier-provided letters of guarantee that standards have been met • Supplier monitoring through periodic audits by retailer or third party • Product monitoring at points under retailer control	• Difficult to maintain accurate, up-to-date specifications on large number of products • Monitoring costly and often impractical because of wide variety of products and global sourcing • No single set of recognized standards • No validated, verifiable auditing system
Temperature-Monitoring Practices	
• Temperature monitoring by retailers at key points within receiving/distributing system and retail facilities • Verification of critical control points (e.g., cooking procedure) conducted and documented • Regular monitoring of display case temperatures • Equipment designs that incorporate automatic temperature control and monitoring systems • Measurement of product temperature at distribution centers and at the retail level	• Lack of temperature-monitoring device specifically designed to meet the needs of retailers • Instruments for use in other environments (e.g., thermocouples, thermisters) being modified slowly • Automatic monitoring devices require retrofitting for retail environments • Employee performance of temperature compliance checks offers only “snapshot” of food’s temperature history • Employee checks may not provide appropriate corrective-action system to address noncompliance
Good Retail Practices (GRPs) and Standard Operating Procedures (SOPs)	
• SOPs identify appropriate food safety steps for each process • HACCP principles used to identify critical and noncritical control steps to minimize food safety risks within each process • Trend toward formalized processes reflecting a relatively stringent adherence to control steps and corrective actions • Application of active managerial controls integrates food safety into day-to-day operations • Retailers adopted enhanced food safety procedures while changing types of foods handled	• Retail settings and processes less structured than manufacturing environment • High retail employee turnover affects performance consistency • Rapid movement of food in and out of retail store where few critical control points exist • Food safety systems designed for processors (e.g., HACCP) not readily applicable to retail • Limited opportunities for pathogen control
Training Programs	
• Availability of supermarket-specific training and certification program “Super Safe Mark” to enhance food safety knowledge and application in-store • Requirements in 33 jurisdictions that trained and/or certified food handlers be present in store during hours of operation	• Regulatory agencies reluctant to recognize nontraditional training programs (e.g., computer-based training) • Need to supplement formal training with in-house training specific to the retail operation • Difficult to maintain trained workforce because of high rate of employee turnover

continued on next page

Textbox 1. (continued)

Methods	Limitations
Training Programs (continued)	
• Components of training include product knowledge, operational procedures, handling practices, sanitation, personal hygiene practices • Certification process overseen by Conference for Food Protection • Formal classroom training, self-paced instructional materials, in-store programs used to deliver current food safety information • Retail industry participates actively in conferences, seminars, workshops to provide continuing education and exposure to new technologies	• Decreasing amount of experience and basic food safety knowledge among people entering workforce makes training more challenging • Advances in science and technology, new food introductions, and changes in consumer preferences (e.g., ethnic foods, organic alternatives) render basic training inadequate to modern demands
Consumer Education	
• FightBAC Campaign developed by the Partnership for Food Safety Education, a public-private endeavor created to decrease foodborne illness through consumer education • Consumer brochures on food safety provided by most retail stores • Special publications to educate children • Consumer information and food safety instructions provided on product labels	• Consumers often overwhelmed with information, including recalls, food safety instructions, and scares of outbreaks and illnesses • Not all information accurate or useful • Consumers' belief in the safety of food • Poor consumer understanding of their own role in ensuring food safety • Difficult to change consumers' behavior

Textbox 2. New food safety intervention strategies under development in food retailing

Methods	Limitations
Sources and Suppliers	
• More consistent food safety standards being adopted • Third-party audits being used to verify compliance • Retailers considering need for international conformity among standards and auditing systems • Suppliers adopting new technologies to change the way foods are packaged and handled • More supplier-packaged or case-ready products may result from the introduction of irradiated foods, bactericidal/static packaging, foods with novel bacterial inhibitors	• Consumer acceptance of new food technologies requires time and effective communication • Consumers may feel less responsible for their own food safety because of adoption of novel technologies • Handling and preparation activities beyond retail could become even more significant contributors to foodborne illness
Hand-Held Temperature-Monitoring Devices with Data-Storage Capability	
• Devices available that measure product temperatures and store results in database • Certain systems allow interaction with other software programs to integrate sanitation assessments, records received, and other data sets with temperature-control data	• High cost of devices • Technology not adapted for easy, reliable, cost-effective use in food industry • Only skilled technicians and retailers with advanced computer skills can use the software programs

Textbox 2. (continued)

Methods	Limitations
Automated Temperature-Monitoring Devices	
• Software products are available that integrate with temperature-maintenance devices within retail facilities • Continual temperature monitoring through direct product contact or product-simulation sensors • Certain systems linked to central computers; may include alarm warning device • Pilot testing within retail industry of both wired and radio frequency devices	• Systems do not interact with hand-held monitoring devices • No interaction with cooking/cooling equipment having temperature-monitoring capability • Many systems too costly for widespread adoption
Time-Temperature Indicators	
• Most TTIs are enzyme-activated sensors that can be used to monitor a product's temperature conditions over time • Fairly inexpensive method of recording information both on products' exposure to temperature abuse and on shelf life • Offer nondestructive, longitudinal temperature profiles of food when placed on product surface or packaging • Can be modified according to time/temperature variables of interest • Certain sensors are color-coded to facilitate use by consumers	• Accuracy and dependability are concerns • Consumer education is required to make indicators useful to customer • Time/temperature as measure of safety versus quality
Rapid Tests for Monitoring Food Safety-Related Conditions	
• Test kits that rapidly detect the presence of potential hazards or unsafe conditions will allow for increasingly scientific application and decision making at retail level	• Accuracy, sensitivity, reproducibility, and affordability are concerns • Retail store does not provide laboratory environment, so in-store test must be safe, easy, and quick • Tests must not require trained technicians • Tests must not present biosecurity concerns
Product Rinses, Chemical Sanitation Systems, and Product Shelf Life Extenders	
• Easily applied, environmentally friendly rinses to limit presence of contaminants such as bacteria and residues • Increasingly reliable, easy-to-use chemical sanitation systems deliver proper concentrations of cleaning and sanitizing agents, minimizing human error • New technologies being tested to retard spoilage bacteria and extend product shelf life	• Product developers frequently do not obtain regulatory approval of products that would allow use by retailers • Retailers resist using new products or systems that lack registration or approval from an authorized agency • Few retail stores have facilities, equipment, or personnel to implement product treatment

tions for all types and levels of food service operation. A balance must be achieved between regulatory standards and practical applications of food safety controls; in addition, applications across business sectors must be equitable.

Existing Intervention Strategies In Food Service

Food safety in food service is optimized through the establishment of systems across the entire food chain. Standards must be driven through partnerships with primary and secondary suppliers; must be reflected in monitoring, to establish credibility; and must influence selection and recognition of suppliers. Because safety in food service operations depends significantly on incoming food ingredients and products, primary suppliers need to extend their interest in food safety backwards down the supply chain, to farmers and to animal producers. At this level, expectations of food service operators include effective animal husbandry and agricultural practices, traceability systems, feed control, and irrigation and drinking water protection, as well as prudent antibiotic use.

Supply chain requirements include designating the individuals responsible for food safety, implementing food safety training programs for all employees, and installing traceability systems for all ingredients, thereby allowing rapid *stock recoveries* (i.e., the removal from commercial distribution of products of unacceptable quality that are still under the control of the producer or its primary distributor) in the event of product noncompliance. To ensure that basic GMPs are being followed, suppliers also need to have in place written, approved, and verified HACCP systems as well as sanitation audit programs.

Food safety controls for distribution networks include (1) a quality inspection program to ensure safety and quality of incoming products, (2) temperature-monitoring systems, (3) sanitation and pest control auditing programs, and (4) traceability programs for rapid stock recoveries. In food service operations, food safety is enhanced through daily checks on key control points such as endpoint cooking temperatures, reheating temperatures, cooling times, sanitation practices, and personal hygiene. Audits by third parties—whether local health departments, corporate representatives, or professional auditors—strengthen food safety systems by enhancing accountability and identifying opportunities for improvement.

Food service operations managers need to be certified through food safety training efforts such as the ServSafe program, which is offered by the U.S. National Restaurant Association Education Foundation. Food service employees must have basic training in food safety and hygiene, and training must increase with responsibility. Inspecting products delivered to food service operations for temperature and package integrity will enhance food safety. Other important steps are establishing a preventive maintenance schedule for storing, handling, and processing equipment and using water filtration for beverages, product wash water, and food ingredient water to protect against failures in water supply systems. Most important, hand washing must be monitored and enforced as a major component of safety programs (Paulson 2000).

Regulatory guidelines such as those in the FDA's Food Code (USFDA 2001) often are incorporated into local laws that drive inspection of food service operations and, in turn, compliance with minimal food safety standards. The capacity of local inspection resources to inspect and to enforce can be limited.

Whereas HACCP-based systems have certain applicability to food service operations, good hygienic practices (GHPs) and ongoing supervision within food service operations are required to address the risk factors of greatest concern—namely, improper holding times and temperatures, contaminated equipment, cross-contamination, and poor personal hygiene (USFDA 2000).

New and Emerging Intervention Strategies in Food Service

On the broadest scale, increased preparation of food before it arrives at the food service operation translates into increased control and decreased food safety risks. For example, creating new product formulations that allow precooking or pasteurization of product surfaces at a manufacturing facility enhances food safety by removing this pathogen-reduction step from among the food service operator's responsibilities. The food service operator simply must reheat the precooked food to achieve the desired quality attributes. Centralization can decrease the risks inherent in processing produce within individual food service units. In most instances, manufacturers of processed products can apply the HACCP system to ensure product safety. Postprocessing contamination still can occur, however. And if a failure occurs at the manufacturing facility, the volume and the potential impact of foodborne illness can be much greater than if failure had occurred at a single-unit operation.

Food service operations that purchase products that can be cooked from frozen rather than from refrigerated states decrease risks by having a greater margin of temperature control during storage. Additionally, certain refrigerated products (e.g., raw poultry and beef) can contain juices more likely to create problems with cross-contamination of other ingredients, foods, or environments. Freezing can injure certain microorganisms, making them more vulnerable to the lethal effects of food service cooking processes.

Equipment manufacturers play a key role in food safety enhancement. More equipment suppliers are embracing the idea of "smart equipment" or "e-kitchens," where equipment is monitored continually on-site and remotely to predict when a failure may occur or to notify operations staff when a failure did, or is about to, occur. Much of this information can feed automatically into the restaurant-based HACCP system, simplifying the daily monitoring activities of food service employees. Smart equipment also notifies service companies when preventive maintenance is required and thereby decreases the possibility that employees will operate unsafe food production equipment.

Using personal computers to conduct food safety audits has significant advantages. Productivity is increased as manual data entry is eliminated and reporting and trend analysis functions are integrated automatically into the software's data management functions. Food safety compliance can be monitored remotely for larger chains, allowing rapid response to noncompliance issues.

Incorporation of antimicrobial agents, such as triclosan or silver, into coatings for food-contact surfaces or directly into the polymers used to make food service gloves and utensils is a novel means of decreasing risk. Antimicrobial agents may not only enhance the efficacy of hand soaps and sanitizers but also are being used in hand lotion products that decrease the detrimental effects of hand soaps and sanitizers on human skin while establishing an antimicrobial barrier between hands and food products. The use of antimicrobials for such purposes has raised concern among certain scientists, however, because of the possibility of introducing additional antimicrobial resistance.

Suppliers of cleaning and sanitation chemical products are improving food safety by developing automated chemical delivery systems that decrease operator error. These systems automatically dispense solutions with the proper amounts of cleaning and sanitizing chemicals, although effective product use and application remain the responsibility of food service operations staff. Time-temperature indicators, though representing a cost in and of themselves, help identify loss of temperature control over significant periods.

Changes for Food Service Organizations

With high annual employee turnover rates, demands on employee food safety training are monumental. Additionally, in certain workplaces where English is a second language, organizations must adapt by providing multilingual instructional materials and visually based training techniques that decrease dependence on verbal skills.

The drive for enhanced food safety efforts in the food service industry begins with customer expectations. The media have focused increasingly on food safety, and so consumers, increasingly aware of unhygienic food-handling practices, are observant and vocal when visiting food service establishments. Many health departments responsible for hygiene and safety in food service establishments are responding to consumer expectations by publishing inspection scores, or posting letter grades or numerical scores prominently in food establishments.

In addition to these competitive pressures, regulatory authorities are promulgating challenging standards—for example, preventing all bare-hand contact with ready-to-eat foods—and establishing new objectives such as HACCP systems for restaurants. Regarding such systems, food service organizations need to adopt a science-based approach to food safety. Validating cooking procedures must be done to establish the safety of this critical process and may involve conducting lethality studies using inoculated samples when appropriate. Once set, cooking processes require routine monitoring and documenting to ensure that daily operations comply with established protocols.

Detection of foodborne outbreaks has progressed so that foodborne illness may be linked to a food vehicle considerably more quickly and accurately than before. Hence, when food service operations are responsible for foodborne illness, the likelihood of establishing a link is high, placing greater demands on food service operations to operate clean, sanitary facilities.

Foodborne transmission of hepatitis A infection can be decreased by vaccinating food service workers. Jacobs and colleagues (2000) estimated that, whereas vaccination of 100,000 food service workers would cost $8.1 million, it would decrease the cost of hepatitis A treatment, public health intervention, and work loss by $3.0 million, $2.3 million, and $3.1 million, respectively. In certain instances (e.g., hepatitis A infections), food-associated viral disease transmission represents a small part of a larger, community-wide problem. Thus, to have real impact, vaccination efforts must be embraced by the entire community.

Consumers

Consumers acquire food through two main channels: retail food markets and food service operations. From retail markets, products of animal origin may be obtained in fresh (raw) or processed forms. At food service operations, foods generally are served fully cooked or ready-to-eat. Many products served to consumers are processed thermally before being sold to food service operations. Thus, consumers eat many meat products to which public food safety interventions already have been applied without always knowing they are doing so. But consumers also purchase foods that have not been subjected to food safety interventions designed to kill pathogens (e.g., raw ground beef) and, for these products, additional food safety interventions must be applied in the home.

Because consumers expect foods that they purchase in a supermarket or restaurant to have been inspected and to be safe, they believe they have little reason to be vigilant about food safety. They make purchase decisions based on many factors, although their information is incomplete. According to Buzby and colleagues (1998), if consumers had perfect information, they would purchase foods that would maximize their well-being. In actuality, however, consumers do not know the level of risk of foodborne illness associated with various foods. Producers and processors know which methods have been applied to enhance product safety, but consumers are, for the most part, unfamiliar with such production and processing methods. Processors lack incentives to provide consumers with such information, in part because it is difficult to charge a premium for "invisible" increases in food safety. In a recent focus group study, consumers stated that implementing HACCP "is the kind of thing they [processors] should be doing anyway. They should want to make sure that the meat is safe, and that should not give them a reason to charge more money for it" (Ford, Penner, and Grunewald 1998).

Existing Consumer Intervention Strategies

Consumer interventions to enhance safety include selecting safe food and handling food properly at home through (1) handwashing, (2) controlling cold and hot temperatures (including cooking sufficiently to kill pathogens), and (3) avoiding cross-contamination. These interventions require a certain level of knowledge, consumer acceptance of safe food-handling responsibilities, and application of at-home safe food-handling practices. Knowledge is necessary but not sufficient to achieve food safety. Researchers comparing food safety knowledge with home food-handling practices have found that knowledge of food safety practices is much greater than the level of application of those practices in the home (Albrecht 1995; Anderson et al. 2001).

Consumers may choose to disregard certain safe food-handling practices (USDA–FSIS 1998b). For example, reasons cited by consumers for not using a thermometer to measure endpoint temperature include "laziness," "inconvenience," and "hassle." These consumers may be exhibiting *optimistic bias* in which individuals assume that they are not vulnerable to hazards and that information is directed at other individuals who possess less knowledge (Frewer, Shepherd, and Sparks 1994). Added to this misconception is the misconception of control. As a result of their personal experiences, many consumers are not convinced that they need to change food-preparation procedures. A frequently heard remark is, "But we've always done it that way and have never made anyone sick" (Schroeter, Penner, and Fox 2001). If consumers believe, no matter how erroneously, that they can control a hazard, and if they have a long personal history of handling a hazard in a certain way, there is little incentive for behavioral change.

Another problem is that higher educational level sometimes is related to unsafe food-handling and food-consumption practices (Anderson et al. 2001; Sean et al. 1999; Zhang, Penner, and Johnston 1999). For example, certain relatively educated consumers enjoy eating products that are risky (e.g., raw oysters, runny eggs, rare hamburger) and choose to take that personal risk. At first, such behaviors seem inconsistent, considering that adoption of health-promoting behaviors (e.g., quitting smoking, increasing exercise) typically also is related to more education. These individuals, however, perceive food hazards and their associated risks as fundamentally different from other health hazards.

Public interventions result from government regulations and/or industry initiatives (e.g., implementing HACCP, washing carcasses, and pasteurizing packaged, processed meats) that frequently are unknown to consumers. On the other hand, meat that has been irradiated must be labeled as such. Consumers will need, as a result, a certain level of knowledge of the process to accept the technology and to purchase the product. Consumer education is a public intervention strategy that can affect private intervention strategies directly. Food safety education occurs through the Partnership for Food Safety Education (the FightBAC campaign) (Partnership 2002) and numerous other programs carried out by entities such as the Cooperative Extension Service at land-grant universities, public health agencies, and schools.

An advantage of public interventions within the industry is that these interventions become standard food safety procedures throughout the United States. For example, many food safety interventions, including those under the 1996 HACCP rule, are highly effective because they are implemented throughout the meat industry. Public interventions by the government and the food-processing industry have prevented certain public health problems related to nutritional intake. For instance, adding iodine to common table salt, which of course is applied to many foods, has had far-reaching impact, resulting in the virtual elimination of goiter in the United States.

Disadvantages of public interventions are that consumers have less control over their food. Not everyone appreciates the technologies applied to food, even if such interventions promote public health. Consumers may view certain interventions as unnecessary. For instance, certain consumers do not favor the use of irradiation because sufficient cooking will kill pathogens (Schroeter, Penner, and Fox 2001).

Consumer Education

Education, with the goal of increasing private application of safe food-handling and food-consumption practices, will continue as a primary public intervention strategy targeted directly at consumers. Publications and fact sheets generated by state Extension services abound, as do food safety educational materials published through educational networks, professional associations, commodity groups, and partnerships. Most materials focus on building consumer knowledge and on urging consumers to follow certain food-handling practices. The question may be asked whether or not these efforts have motivated consumers to implement private interventions at home.

According to Daniels and colleagues (2001), consumer food safety education has been effective to a certain extent. Consumers today have a greater awareness of food safety; however, they tend to misperceive their own roles in preventing foodborne illness. They often believe that foodborne illness is caused by someone in another part of the food system (Penner, Kramer, and Frantz 1985; Williamson, Gravani, and Lawless 1992). They frequently do not perceive that foodborne illnesses have serious or long-term consequences, believing such illnesses to be generally mild and acute (Fein, Jordan, and Levy 1995). For consumers to make safe food-consumption choices and to apply appropriate food-handling practices in their homes, they must perceive that the mishandling of food can have direct negative consequences on their own and their family's health (Schafer et al. 1993).

Health communications researchers have found that people often reject a message about food and food handling because they subscribe to *lay theories*—beliefs or understandings held by persons without expert knowledge of a field, that run counter to scientific understanding (Furnham and Hume-Wright 1992; Gordon 1995). One example of a maladaptive lay theory related to food is that one can tell by sight, smell, or taste when food is contaminated. Gordon (1995) studied the relation of lay theories to the maladaptive food-handling behavior of thawing meat products at room temperature. Four lay theories emerged from participant responses: (1) bacteria make one ill; (2) cooking kills bacteria; (3) one can identify unsafe meat products by smell, appearance, or taste; and (4) meat products are clean when purchased. The first two theories are not entirely inaccurate, but adherents often fail to recognize other causes of illness and the risk of contamination and recontamination after food is cooked. The last two lay theories are both inaccurate and maladaptive.

To be effective, food safety education messages not only must provide factual scientific information but also must help consumers set aside maladaptive lay theories. Rowan (1991) presented five key features of messages that can be used to overcome such theories: (1) messages must make the maladaptive lay theories explicit, (2) communicators must acknowledge the evident plausibility and adequacy of the lay theory, (3) the lay theory's inadequacy must be demonstrated, (4) the orthodox theory must be presented, and (5) the orthodox theory's greater adequacy must be established.

This type of studied approach is lacking in most public food safety education campaigns. If, as Bruhn (1997) has stated, consumers need to appreciate the gravity of foodborne disease, then adult-based food safety education programs should be presented in effective ways, incorporating concepts learned from research and from successful educational efforts aimed at other health threats. Bruhn also recommended that food safety messages be consistent, science based, frequent, and personalized. The gap between current food safety education efforts and the ideal for effective education remains large.

CONCLUSIONS

1. A strategic approach, such as quantitative microbial risk assessments, is needed to identify critical points within the food continuum at which effective interventions will have the greatest impact on decreasing public health hazards.

2. Improving the safety of foods of animal origin begins at the farm. Innovative intervention strategies are needed to control pathogens in animal production.

3. New intervention strategies that decrease public health hazards—strategies such as on-farm treatments, antimicrobial treatments, food additives, and processing technologies—should receive expedited

review by regulatory agencies.

4. Good agricultural practices are needed that effectively decrease pathogens during production and include effective intervention strategies for beef, dairy, pork, egg, and poultry producers.

5. On-farm food safety practices should be developed and implemented based on management programs used in food-manufacturing facilities. Practices on the farm used to produce milk and meat should reflect the latest science in animal health and well-being, public health, environmental health, and medical ecology and should contribute to an economically viable industry. All sectors of agriculture must have sufficient funding to refine management practices and to train producers, veterinarians, and allied industry personnel in leading-edge management techniques.

6. Significant changes in animal husbandry should be evaluated for their potential impact on public health before the changes are implemented. Then as changes are implemented, a system is needed to verify that the public health assessment was accurate. An example is the hypothesis that intense rearing of livestock increases the transmission and prevalence of foodborne pathogens among animals that may be stressed under such conditions and thereby increases human exposure through higher levels of pathogens on raw meat and poultry.

7. The feed industry should develop processes for eliminating pathogens from dry feed materials that cannot be pelletized. All treated feed materials should be handled in ways that prevent contamination by moisture and pests.

8. On-farm solutions for manure management should include ground- and surface-water protection from contamination with pathogens and excessive nutrients.

9. Success in the global marketplace will require harmonization among global food safety standards and food safety systems such as good agricultural practices for beef, dairy, egg, pork, and poultry production.

10. Additional educational efforts are needed for producers who raise livestock, poultry, and animal-food products regarding effective interventions to decrease pathogen contamination on the farm.

11. More effective strategies for educating consumers to apply interventions in preparing foods must be developed and evaluated. New strategies must be used, perhaps including mass media campaigns that capture people's attention and encourage behavioral change. Simply providing scientific information is not highly effective.

12. Additional effective food safety interventions in food retail and food service operations should be developed and implemented.

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E-mail: cast@cast-science.org