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Review

A Review of the Incidence and Transmission of *Listeria monocytogenes* in Ready-to-Eat Products in Retail and Food Service Environments

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ABSTRACT

Contamination of ready-to-eat products with *Listeria monocytogenes* may occur at several stages before consumption. Accessibility to the public and relatively limited control interventions at retail and food service establishments (compared with the processing sector of the food industry) and the lack of a specific regulatory framework increase the likelihood of introduction of this pathogen into some foods in these establishments. This review is a compilation of available information on the incidence and transmission of *L. monocytogenes* through ready-to-eat products at the retail and food service level. The potential transmission of *L. monocytogenes* within retail and food service operations has been indicated in epidemiological investigations and by survey data. Potential sources of the organism in these operations include the environment, food handlers, and incoming raw ingredients or processed products that have become contaminated after the lethality treatment at the manufacturing facility. *L. monocytogenes* may be present at retail and food service establishments in various ready-to-eat products, both prepackaged and those packaged in the store, and occasionally at high concentrations. This issue dictates the need for development and application of effective control measures, and potential control approaches are discussed here. Good manufacturing practices, appropriate cleaning, sanitation and hygiene programs, and temperature control required for prevention or inhibition of growth of the pathogen to high levels are critical for control of *L. monocytogenes* in the retail and food service sector. A comprehensive food safety system designed to be functional in retail and food service operations and based on the philosophy of hazard analysis and critical control point systems and a series of sound prerequisite programs can provide effective control of *L. monocytogenes* in these environments. However, competent delivery of food safety education and training to retail and food service managers and food handlers must be in place for successful implementation of such a system.

Since the early 1980s, when the foodborne pathogen status of *Listeria monocytogenes* was established *(148, 234),* extensive efforts have been undertaken by both the food industry and regulatory agencies for control of this organism in the food production, processing, distribution, and consumption chain *(248).* Because of its natural presence in decaying plant material, soil, animal feces, sewage, water, and animal feeds (particularly silage), *L. monocytogenes* can be transferred through multiple routes to animal and plant food products *(236).*

Listeriosis, the infection caused by *L. monocytogenes,* is a rare human disease, but it may have serious clinical manifestations for susceptible population groups (i.e., the elderly, fetuses, neonates, and immunocompromised individuals); 20 to 30% of the cases are fatal *(65, 214).* According to preliminary surveillance data available from the Centers for Disease Control and Prevention (CDC) Foodborne Illness Active Surveillance Network (FoodNet), the overall incidence of listeriosis in the United States in 2005 was 3.0 cases per million people *(42),* and the corresponding incidence in 2004 was 2.7 cases *(41).* The pathogenesis and virulence determinants of *L. monocytogenes* have been reviewed by Dussurget et al. *(70)* and Liu *(153).* Although the risk of listeriosis is higher when the product is contaminated with high levels of the organism *(46, 170),* the infectious dose of the pathogen is also dependent on the type of food product, strain virulence, and host susceptibility *(173)*; therefore, relatively lower doses may still cause infection in high-risk populations *(83, 163).* Information on various aspects of *L. monocytogenes* and listeriosis has been presented by McLauchlin et al. *(173)* and in a comprehensive report by the International Life Sciences Institute Risk Science Institute (ILSI RSI) Expert Panel *(123)* focused on the identification of strategies for the reduction of foodborne listeriosis using a risk-based approach. The third edition of the book *Listeria, Listeriosis and Food Safety* by Ryser and Marth *(222)* provides a comprehensive overview of foodborne listeriosis, summarizing information relative to *L. monocytogenes* incidence and pathogenesis, illness outbreaks, detection methods, subtyping, and risk assessment.

Items from all food categories (i.e., meat products, dairy products, seafood, and produce) have been implicated in outbreaks of listeriosis. Foodborne illness outbreaks usu-

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ally are the outcome of coincidental events and conditions encountered simultaneously at various points in the food chain (e.g., food or environmental source of contamination and conditions that favor pathogen growth). Therefore, all sectors of the food industry play a role in the assurance of food safety *(14)*. Depending on the type of product (raw or processed) and its intended use (e.g., requires further heating or is ready to eat), the stage in the food chain where contamination occurs may be associated with the level of the organism to which consumers ultimately will be exposed *(123)*. Epidemiological data indicate that certain food products are more likely to be associated with listeriosis outbreaks than others; such foods are products consisting of raw ingredients or that are eaten raw, products not subjected to a listericidal process, and products susceptible to postlethality contamination that have an extended shelf life under refrigeration and allow pathogen growth, particularly when intended to be consumed without further cooking by vulnerable populations *(18)*. The demands of modern life and modern eating habits favor development and availability of such products.

Societal and dietary changes during recent decades, emphasizing reduced exposure to antimicrobial hurdles, have led to corresponding changes in the types and sources of food products consumed *(49, 111, 276)*. Increased consumption of foods handled by food workers in commercial processing and retail or food service establishments also has been recognized as a contributing factor, along with changes in the epidemiology of foodborne diseases, to greater consumer exposure to foodborne pathogens *(49, 111)*. Surveillance and epidemiological investigations have demonstrated a potential association between food handling at retail and food service establishments and the incidence of foodborne illness *(13, 31, 111, 115, 125, 172, 207, 235)*. Although the incidence, persistence, and transmission dynamics of *L. monocytogenes* in food-processing environments have been studied extensively *(15, 72, 90, 91, 131, 159, 166, 175, 197, 200, 219, 228, 230, 238)*, data regarding the role of retail and food service environments or operations (e.g., grocery stores, delicatessens, and restaurants) in transmission of this pathogen are limited *(123)*.

Meat processing operations undergo continuous inspection, whereas the retail and food service industry is inspected less frequently *(165)*. The intensive efforts that have been made during the last decade by food manufacturers to comply with regulations designed to control *L. monocytogenes (250)* may have rendered current food-processing environments less likely sources of the organism than they were in the past. Establishments in the United States that produce ready-to-eat (RTE) meat or poultry products need to develop and implement effective control measures to meet the zero-tolerance policy and requirements of the final rule established by the U.S. Department of Agriculture Food Safety and Inspection Service (USDA-FSIS) *(250)*. The lack of a similarly strict regulatory framework for the retail and food service sector and the relatively limited application of antimicrobial controls in these environments raise concerns. According to the findings of two surveys in the United Kingdom, manufacturers were more likely than retailers or caterers to use hazard analysis and critical control point (HACCP) systems and to provide training and food hygiene courses to food handlers *(187, 188)*. Unique aspects of retail and food service environments that may hinder development and application of appropriate control measures include the complexity, variety, and highly dynamic character of operations, the fact that such premises are open to the public, the need to display, slice, and repackage certain products, high dependency on part-time or temporary food handlers, and the associated high employee turnover *(174, 187, 188, 212)*.

This review provides a compilation of available knowledge on the incidence (prevalence, subtypes, and contamination levels) of *L. monocytogenes* in RTE food products (meat and poultry, seafood, dairy, and produce) at retail and food service premises and of information on the transmission of the pathogen in these settings. Epidemiological and microbiological food survey data demonstrating the role of retail and food service operations in transmission of the organism and potential routes of contamination of RTE foods handled in these environments are discussed. The information presented here focuses on RTE products (raw or processed) that in general do not undergo any cooking step at the retail or food service level but are likely to be handled (e.g., sliced, cut, or repackaged) or used in the preparation of other RTE foods (e.g., salads or sandwiches).

For factory-packaged foods sold in the original container, presence of the pathogen indicates contamination during manufacturing. Nevertheless, plant-contaminated products may serve as vehicles for pathogen transmission within retail or food service premises when these products are opened and handled in these environments. Thus, information on both prepackaged RTE products and RTE products that are opened or packaged in the store is presented here. Potential approaches for *L. monocytogenes* control in retail and food service operations aimed at prevention of contamination of RTE foods or prevention of growth of the pathogen to high levels also are discussed.

PREVALENCE OF *L. MONOCYTOGENES* IN RTE PRODUCTS AT RETAIL AND FOOD SERVICE ESTABLISHMENTS

Listeria spp. have been isolated from a variety of retail foods, including raw foods, processed products that require cooking prior to consumption, and foods intended to be consumed without prior heating *(51, 61, 88, 107, 231, 262)*. According to the findings of a survey of foods sampled in food processing plants, supermarkets, and small food markets in Italy between 1990 and 1999, half of the *L. monocytogenes*–positive samples were RTE foods, in particular dairy products, seasoned meats, fish products, and vegetables *(92)*. However, regardless of prevalence rates, RTE foods pose a higher risk for listeriosis than do raw foods because raw foods generally are cooked before they are consumed.

L. monocytogenes and *Listeria innocua* are generally the *Listeria* species most frequently isolated from RTE foods in retail and food service premises, including meat and poultry products *(66, 81, 101, 240, 265)*, fish and seafood products *(100, 109, 129),* dairy products *(57, 82, 167, 208, 262),* and produce *(62, 112, 245).* Additional *Listeria* species isolated from a variety of RTE foods are *L. welshimeri, L. grayi, L. seeligeri,* and *L. ivanovii (1, 57, 61, 66, 81, 84, 88, 98, 107, 112, 134, 208, 226, 231, 243, 247, 259, 262, 266, 272).* Co-occurrence of multiple *Listeria* species also has been documented *(7, 107).* Although *L. monocytogenes* is the major pathogenic species, presence of any type of *Listeria* in RTE foods, excluding probably produce, may be indicative of poor hygiene or the potential presence of the pathogen *(226, 245),* and it has been suggested that corrective actions should be implemented following recovery of any *Listeria* species (*7).*

Various *L. monocytogenes* prevalence rates in RTE foods sampled from retail and food service premises have been reported (Tables 1 through 4), most likely reflecting geographic differences and differences in the regulatory policies and control measures in different countries. The protocols and media used for isolation of the organism, and food handling conditions prior to analysis, also may affect the results *(2, 7, 132).*

Meat and poultry products. A fatal case of infection associated with consumption of turkey franks was the first documented implication of a meat product as the source of clinical listeriosis in the United States *(36).* Since that case, several outbreaks and sporadic cases of listeriosis linked to meat products have been documented worldwide. Recent major outbreaks associated with consumption of hot dogs and delicatessen meat and poultry products in the United States *(37, 38, 40)* demonstrated the public health significance and the economic implications of this pathogen for the meat industry. Despite the fact that in some cases *L. monocytogenes* has not been detected in processed meat samples collected from processors, retailers, or restaurants *(17, 177, 223, 243, 259),* there are numerous reports of this organism in RTE meat and poultry products from retail or food service establishments (Table 1).

Raw meats and particularly raw poultry are important sources of *Listeria* spp., especially *L. monocytogenes (17, 27, 32, 34, 43, 50, 69, 84, 90, 91, 177, 220, 271).* Although a higher incidence of the pathogen was found in samples of raw meats than in samples of heat-treated meats collected from stores and restaurants in Budapest *(139),* Ng and Seah *(191)* reported that 42.9% of *L. monocytogenes*–positive samples of foods from restaurants, fast food outlets, supermarkets, and manufacturers in Singapore were RTE items and 66.7% of these items were meat products. Raw meat and poultry are not considered at high risk for causing foodborne listeriosis provided that adequate cooking precedes consumption and that cross-contamination is avoided. Nevertheless, raw or insufficiently cooked meats may serve as sources of cross-contamination of products that are intended to be consumed without heat treatment, and along with inadequate cleaning and sanitation, have been recognized as the main sources of postprocessing contamination of RTE meat products *(51, 132, 228).*

The presence of *L. monocytogenes* in cooked meat products is most likely the result of recontamination following processing, which may occur during additional handling such as peeling, slicing, and repackaging *(32, 132, 211, 248, 265).* For RTE meat and poultry products such as delicatessen meats that are handled in retail and food service environments, recontamination or cross-contamination can occur in these environments. In the risk assessment undertaken by the U.S. Food and Drug Administration (FDA), the USDA-FSIS, and the CDC, delicatessen meats were categorized at the highest level of risk of serious illness and death associated with consumption of RTE foods potentially contaminated with *L. monocytogenes,* on both a per serving and per annum basis *(256).*

Numerous reports on the incidence of *Listeria* spp. in processed meat products have been published *(127).* Wilson *(269)* tested RTE foods collected from retail displays in Northern Ireland between 1994 and 1995 and reported meat product contamination rates ranging from 1% (pâté) to 11% (chicken); *L. monocytogenes* was found in 5% of chicken samples and represented 45% of all isolated listeriae. Prevalence in RTE meats appears to depend on the type of product and its manufacturing process (thermally processed or fermented), composition, and intrinsic characteristics *(132).* Higher *L. monocytogenes* contamination rates have been documented in retail processed meats with high pH and water activity and low nitrite concentration *(101, 265),* but detection of the organism often has not been successful in fermented meat products *(2, 101, 220).* However, high prevalence of the pathogen has been documented in some cases in fermented sausages and salami *(4, 32, 59, 84).* Angelidis and Koutsoumanis *(7)* conducted a survey of packaged precut RTE meats from supermarkets in Greece in 2004 and reported a similar *L. monocytogenes* incidence in fermented (8.2%) and heat-treated (8.1%) products. Presence of *L. monocytogenes* in RTE meat products may be a concern even if conditions for growth of the organism are not favorable; some cells may survive in sufficient numbers to cause infection in sensitive individuals. Products that do not support growth, such as salami, may serve as means of transmission of the pathogen during handling (e.g., slicing) and allow cross-contamination of products that support growth *(263).*

Since the late 1980s, pâté has been recognized as a potential source of *L. monocytogenes,* and contamination rates as high as 35% have been reported for samples from retail and distribution outlets *(185, 186).* Pâté and meat spreads have been ranked as RTE foods associated with a high risk for listeriosis on a per serving basis and moderate risk on a per annum basis *(256).* A higher incidence of *L. monocytogenes* has been reported for seafood than meat and poultry pâté *(74).* The inability of the organism to grow during refrigerated storage of such naturally contaminated retail products has been documented *(81).* However, meat and poultry pâtés may be a concern for *L. monocytogenes* transmission in retail and food service operations. Presence of the pathogen in prepackaged pâté may be due to insufficient cooking or contamination after lethality treatment *(186).* Because this particular product often is sold at delicatessen counters where amounts are cut from open containers or loaves, cross-contamination by food handlers or shared utensils is likely *(193).* Differences in prevalence rates of *Listeria* spp. between prepackaged and in-store–packaged RTE meat and poultry products have been documented *(66, 99, 117, 186, 240, 267).* The type of handling that RTE meats receive also may influence contamination with *L. monocytogenes*; significantly higher prevalence of the pathogen was reported in products cut in cubes (61.5%) compared with sliced products (4.6%) in a survey of retail packaged RTE meats *(7).* Trends in the prevalence and levels of *L. monocytogenes* associated with the method of sale (prepackaged or handled and packaged at retail premises) of RTE meats are discussed in detail below.

Seafood products. Although *Listeria* species, including *L. monocytogenes,* have been isolated from various processed seafood products *(64),* such products primarily have been associated with sporadic cases and small outbreaks of listeriosis *(216).* Listeriosis outbreaks have been linked to consumption of products such as gravad or cold-smoked rainbow trout and smoked mussels *(29, 76, 181).* The risk associated with seafood depends on the origin and microbiology of the product and on the processing and handling practices that are used before the product is consumed *(216).* High incidence of *Listeria* spp. in RTE seafood from retail establishments has been documented *(80, 129, 269)* as has the ability of *L. monocytogenes* to grow during refrigerated storage of naturally contaminated products *(80).* Prevalence rates of *L. monocytogenes* in retail RTE seafood products are summarized in Table 2.

Lightly preserved products such as smoked fish often are contaminated with *L. monocytogenes,* demonstrating a potential high risk of transmission of listeriosis *(19, 120, 197).* Vitas et al. *(262)* reported that 28% of the samples of smoked salmon collected from supermarkets in Spain were contaminated with *L. monocytogenes,* a prevalence higher than that for other RTE products (i.e., cooked meats, cured meats, and soft cheeses). Contamination rates tend to be higher in cold-smoked than in hot-smoked fish products (Table 2), but postprocessing contamination of hot-smoked products may result in faster proliferation of the organism during storage (depending on storage temperature) due to the absence of competitive microflora *(133, 155, 160).* Loncarevic et al. *(155)* investigated the incidence and levels of *L. monocytogenes* in fish products obtained from retail markets in Sweden and reported that gravad fish had the highest prevalence (20.7%) followed by cold-smoked fish (11.5%); however, the highest pathogen concentration (132,000 CFU/g) was found in a hot-smoked rainbow trout sample. Similarly, in a subsequent study in Finland with retail vacuum-packaged (sliced or nonsliced) fish products, *L. monocytogenes* primarily was isolated from sliced cold-smoked and gravad rainbow trout samples *(160).* Therefore, such products should be considered high-risk foods and should be handled carefully and stored at low temperatures for only short periods of time.

Evaluation of samples purchased from supermarkets in Japan revealed significantly higher *L. monocytogenes* isolation frequencies in processed seafood products (smoked and fermented) than in raw fish, but some product-specific trends also were observed; the incidence of the organism was higher in salmon (raw salmon and processed salmon products; 12.5%) than in other fish and seafood products (3.8%) *(273).* Although the majority of published studies have been conducted to determine the incidence of *L. monocytogenes* in vacuum-packaged products, differences in contamination rates associated with type of packaging have been reported in some cases (Table 2). Dominguez et al. *(66)* reported higher prevalence of the pathogen in opened (28.5%) than in vacuum-packaged (17.7%) samples of cold-smoked salmon in a study conducted in Spain in 2000, whereas higher incidence of the organism in in-store–packaged seafood salads (6.9%) than in manufacturer-packaged salads (1.4%) was reported in a large survey undertaken in the United States during 2000 and 2001 *(99).* Failure to detect *L. monocytogenes* in retail seafood products also has been documented. The pathogen was not detected in dried seafood (i.e., shrimp, squid, and smoked mussels) from supermarkets and quarantine stations in Korea *(17)* or in any of the cold-smoked salmon and trout samples analyzed in a survey undertaken in Spain, where vacuum-packaged products were obtained from supermarkets after 3 weeks of storage at 2 ± 1°C *(100).*

When assessing the risk of listeriosis associated with consumption of seafood products, dietary habits driven by social or cultural differences also must be taken into account. Raw seafood products are sold and consumed as RTE foods in some parts of the world, particularly in Asian countries. Ryu et al. (*223)* assessed the incidence of *L. monocytogenes* in Japanese retail products in 1990 and found contamination rates as high as 16.7% in raw seafood products. In a survey of seafood collected from retail stores in Japan between 2002 and 2003, *L. monocytogenes* was present in 14.3% of samples of raw minced tuna, and in 10.0 and 11.4% of salmon and cod roe samples, respectively (*108).* Fish roe, particularly fresh roe (which may be subject to more extensive handling at the retail level than frozen product), is a potential source of *L. monocytogenes* and, because it is frequently consumed raw, may constitute a vehicle for human infections *(108, 179).*

Dairy products. *Listeria* spp. have been detected in various retail dairy products *(143, 269).* The public health concerns associated with the presence of *L. monocytogenes* in dairy products have been demonstrated by listeriosis outbreaks linked to milk and milk products, including "pasteurized" milk, chocolate milk, soft cheese, and butter *(173).*

Raw milk may be one means of transmission of the pathogen, which may be introduced during the milking process (from asymptomatic mastitic animals or from environmental sources) or during manufacturing of dairy products *(141, 154, 201).* Raw milk, provided that it is not consumed as is, is a concern if used in the unpasteurized state for the manufacture of dairy products such as cheeses intended to be consumed without heat treatment *(154).* Because normal pasteurization procedures are sufficient to destroy *L. monocytogenes* in milk *(28),* the presence of the organism in properly pasteurized products is most likely the result of

TABLE 1. *Prevalence of* Listeria monocytogenes *in ready-to-eat meat and poultry products*

Product	Country	Source	Prevalence[a]	Reference
Aspic	Belgium	Supermarkets	4/48 (8.3%; prepackaged) 1/67 (1.5%; not prepackaged)	*258*
Beef (cured)	Belgium	Supermarkets	2/43 (4.7%; prepackaged)	*258*
Brawn	Hungary	Food stores, restaurants, caterers	13/55 (23.6%)	*139*
Chicken	New Zealand	Retail outlets	2/16 (12.5%)	*117*
Corned beef	Australia	Retail stores	52/72 (72.2%; vacuum packaged)	*101*
Delicatessen products[b]	France	Supermarkets	8/37 (21.6%)	*194*
Frankfurters and wieners	United States	Supermarkets	7/93 (7.5%; 19 brands) 17/24 (71.0%; 1 brand)	*265*
	Canada	Supermarkets	5/100 (5.0%; beef, vacuum packaged) 3/100 (3.0%; chicken, vacuum packaged)	*27*
Ham	Australia	Retail stores	24/71 (33.8%; vacuum packaged)	*101*
	Ireland	Retail outlets	2/20 (10.0%)[c]	*240*
	Hungary	Food stores, restaurants, caterers	1/3 (33.3%)	*139*
	Belgium	Supermarkets	15/1,069 (1.4%; cooked, BS) 54/879 (6.1%; cooked, AS) 20/169 (11.8%; cured, prepackaged)	*258*
	Chile	Industries, markets, restaurants, hospitals	1/31 (3.2%)	*51*
	Portugal	Retailers, producers	1/4 (25.0%; cooked) 1/44 (2.3%; dry cured)	*177*
	New Zealand	Retail outlets	1/104 (1.0%; prepackaged)	*272*
	Greece	Supermarkets	1/27 (3.7%; cooked)[d] 1/6 (16.7%; fermented)[d]	*7*
Loin	Belgium	Supermarkets	3/87 (3.5%; cooked, BS) 13/127 (10.2%; cooked, AS) 24/121 (19.8%; cured, prepackaged)	*258*
Luncheon meats[b]	Australia	Retail stores	2/13 (15.4%; vacuum packaged)	*101*
	United States	Retail markets	82/9,199 (0.9%) 0.4% (prepackaged) 2.7% (in-store packaged)	*99*
Minced meat	Belgium	Supermarket	8/19 (42.1%; prepackaged) 2/3 (66.7%; not prepackaged)	*259*
Mixed-source meats	New Zealand	Retail outlets	8/76 (10.5%)	*117*
Pastrami (pastirma)	Turkey	Retail markets	2/25 (8.0%; vacuum packaged)	*4*
Pâté	Wales	Retail and distribution outlets	46/155 (30.0%; display) 23/50 (46.0%; vaccum packaged)	*186*
	England, Wales	Shops, supermarkets, other outlets	37/1,804 (2.0%; meat) 17/528 (3.0%; poultry)	*193*
	Belgium	Supermarkets	6/217 (2.8%; prepackaged) 6/130 (4.6%; not prepackaged)	*258*
	Chile	Industries, markets, restaurants, hospitals	2/160 (1.3%)	*51*
	Spain	Retail outlets, supermarkets	4/42 (9.5%; prepackaged) 6/140 (4.2%; opened)	*66*
	Cyprus	Production sites, retail outlets	3.0%	*73*
	United Kingdom	Catering and retail premises	1.0% (meat) 2.0% (poultry)	*74*
	New Zealand	Supermarket outlets	1/300 (0.3%; prepackaged)	*272*
Pork	New Zealand	Retail outlets	1/34 (2.9%)	*117*
Poultry	Belgium	Supermarkets	2/32 (6.3%; whole, cooked) 2/13 (15.4%; whole, cured) 9/100 (9.0%; minced, prepackaged) 3/59 (5.1%; minced, not prepackaged)	*258*
	Canada	Supermarkets	3/100 (3.0%)	*27*

TABLE 1. *Continued*

Product	Country	Source	Prevalence[a]	Reference
Processed meats[b]	Denmark	Retail	77/328 (23.5%; preserved)[d]	*196*
			45/772 (5.0%; heat treated)[d]	
	Spain	Retail	34/369 (9.2%)[e]	*1*
	Portugal	Markets, supermarkets	10/47 (21.0%)[f]	*107*
	Cyprus	Production sites, retail outlets	34.0%	*73*
	United Kingdom	Catering premises	13/3,455 (0.4%)	*96*
	United Kingdom	Catering and retail premises	60/2,874 (2.1%)	*74*
Sausages				
Blood sausages	Belgium	Supermarkets	12/137 (8.8%; prepackaged)	*258*
			2/18 (11.1%; not prepackaged)	
	Portugal	Retailers, producers	1/9 (11.1%)	*177*
Fermented sausages	Canada	Retail establishments	6/30 (20.0%)	*84*
	Yugoslavia	Supermarkets, butcher shops	4/21 (19.0%)	*32*
	Turkey	Retail markets	5/25 (20.0%; vacuum packaged)	*4*
	Canada	Supermarkets	4/100 (4.0%; vacuum packaged)	*27*
Hot-smoked sausages	Yugoslavia	Supermarkets, butcher shops	3/14 (21.0%; vacuum packaged)	*32*
Liver sausages	Hungary	Food stores, restaurants, caterers	3/22 (13.6%)	*139*
Salami	Brazil	Retail markets	6/81 (7.4%)	*59*
	Turkey	Retail markets	4/25 (16.0%; vacuum packaged)	*4*
	Greece	Supermarkets	3/30 (10.0%)[d]	*7*
Spanish-style sausage	Portugal	Retailers, producers	1/27 (3.7%)	*177*
Other products				
Chicken salad	Belgium	Supermarkets	41/152 (27.0%)	*258*
Ham salad	Belgium	Supermarkets	33/159 (20.8%)	*258*

[a] Number of positive samples/number of samples tested (% positive samples). BS, before slicing; AS, after slicing.
[b] Information on the prevalence of *L. monocytogenes* in specific products was not available.
[c] Open (not prepackaged).
[d] Packaged under vacuum or modified atmosphere.
[e] Sliced and packaged by retailer just before sale.
[f] Packaged under modified atmosphere.

postpasteurization contamination *(55).* Regardless of contamination routes, presence of *L. monocytogenes* in RTE dairy products is a concern because of the potential for pathogen growth or long-term survival, depending on the type of product, under refrigeration conditions *(177, 218, 266).*

Lower prevalence of *L. monocytogenes* has been reported in dairy products than in other RTE foods, including seafood and processed meats *(34, 99).* In a survey undertaken by the International Dairy Foods Association in the United States in 2000, very low incidence (0.018%) of *L. monocytogenes* was found in pasteurized fluid milk sold in retail premises; only 1 of 5,519 samples tested positive for the pathogen *(89).* Samples from various dairy products have been found to be free of *L. monocytogenes (17, 51, 98, 177, 191, 271).* However, cheeses appear to be contaminated with *Listeria* spp. more frequently than milk *(106, 107),* and retail cheeses, particularly soft cheeses, have been found to be contaminated in several instances (Table 3).

L. monocytogenes may survive during manufacture of soft cheeses *(221)* from raw milk. Proliferation of the pathogen during subsequent storage of such cheeses is favored by their intrinsic properties (i.e., higher pH and water activity and lower salt concentration compared with other types of cheese) *(60).* Van Coillie et al. *(259)* reported a high prevalence of the pathogen both in raw (46.7%) and pasteurized (60.0%) milk cheeses purchased (not prepackaged) at one retail market in Belgium. Such high rates of contamination may be due to presence of the organism in raw materials and/or cross-contamination during handling (i.e., cutting or slicing) at the retail level. Ice cream is another RTE dairy product that may be contaminated with pathogens during handling at the retail and food service level *(217, 266).*

Differences in the incidence of *Listeria* spp. associated with type of packaging or serving characteristics of dairy products have been demonstrated in some cases (Table 3). Warke et al. *(266)* reported a higher incidence of *Listeria* spp. in open than in packaged ice cream sold in Indian retail markets. However, Guerra et al. *(107)* reported a higher *Listeria* spp. prevalence in wrapped than in ‘‘loose’’ retail cheeses in Portugal; *L. monocytogenes* was isolated only from cheeses sold wrapped. In a survey of retail food products in the United Arab Emirates, half of the *Listeria*-positive cheese samples were from cheeses sold as ‘‘loose’’ and the other half were from cheeses in cans sealed by the manufacturer *(98).* Loncarevic et al. *(154)* reported a similar incidence of *L. monocytogenes* in whole cheeses and

TABLE 2. *Prevalence of* Listeria monocytogenes *in ready-to-eat seafood products*

Product	Country	Source	Prevalence[a]	Reference
Fermented seafood	Japan	Supermarkets	2/9 (22.2%)	*273*
Gravad fish	Iceland	Retail	5/11 (45.0%)[b]	*109*
	Sweden	Retail markets	12/58 (20.7%; vacuum packaged)	*155*
	Finland	Retail outlets	10/31 (32.0%; S, vacuum packaged) 4/12 (33.0%; NS, vacuum packaged)	*160*
Pâté (seafood)	England, Wales	Shops, supermarkets, other outlets	9/122 (7.0%)	*193*
	United Kingdom	Catering and retail premises	10.0%	*74*
Roe	Finland	Retail stores, shops, markets	6/34 (18.0%; fresh) 1/48 (2.1%; frozen and thawed)	*179*
	Japan	Retail stores	7/67 (10.4%)	*108*
Salads (seafood)	Belgium	Supermarkets	99/362 (27.3%)	*258*
	United States	Retail markets	115/2,446 (4.7%) 1.4% (prepackaged) 6.9% (in-store packaged)	*99*
	Belgium	Supermarkets	2/4 (50.0%; fish salad) 4/4 (100.0%; crab salad) 3/6 (50.0%; smoked salmon salad) 3/12 (25.0%; imitation crab salad) 4/14 (28.6%; tuna salad)	*259*
Shrimp	Canada	Retail	4/20 (20.0%)	*80*
Smoked fish	Iceland	Retail	1/10 (10.0%)[b]	*109*
	New Zealand	Retail outlets	8/12 (66.7%)	*117*
	Switzerland	Not specified	49/434 (11.3%; cold smoked) 58/691 (8.4%; hot smoked)	*128*
	Sweden	Retail markets	3/26 (11.5%; cold smoked, vacuum packaged) 1/66 (1.5%; hot smoked, vacuum packaged)	*155*
	Finland	Retail outlets	5/20 (25.0%; cold smoked, S, vacuum packaged) 4/42 (9.0%; cold smoked, NS, vacuum packaged) 1/42 (2.0%; hot smoked, NS, vacuum packaged)	*160*
	Finland	Retail outlets	5/30 (17.0%; cold smoked, vacuum packaged) 1/48 (2.0%; hot smoked, vacuum packaged)	*131*
	Japan	Retail stores	5/92 (5.4%)	*121*
	Japan	Supermarkets	3/13 (23.1%)	*273*
	Spain	Retail outlets	14/52 (26.9%; vacuum packaged)	*1*
	Spain	Retail outlets, supermarkets	12/42 (28.5%; opened)[c] 16/90 (17.7%; vacuum packaged)[c] 10/38 (26.3%; vacuum packaged)[d]	*66*
	Cyprus	Production sites, retail outlets	18.0%	*73*
	India	Fish market	10/20 (50.0%)	*129*
	Belgium	Supermarkets	8/42 (19.0%; salmon) 1/2 (50.0%; sprat) 2/4 (50.0%; mackerel) 6/18 (33.3%; halibut)	*259*
	Spain	Supermarkets	28/100 (28.0%)	*262*
Smoked mussels	New Zealand	Retail outlets	5/14 (35.7%)	*117*
	Korea	Supermarkets, quarantine stations	3/68 (4.4%; frozen product)	*17*
Smoked seafood[e]	United States	Retail markets	114/2,644 (4.3%)	*99*
Other products				
Boiled crawfish	United States	Shops, grocery stores	1/31 (3.2%)	*169*
Cold-salted trout	Finland	Retail outlets	16/32 (50.0%; vacuum packaged)	*131*
Cooked shellfish	Chile	Industries, markets, restaurants, hospitals	14/209 (6.7%)	*51*

[a] Number of positive samples/number of samples tested (% positive samples). S, sliced; NS, not sliced.
[b] Vacuum packaged or packaged in plastic containers.
[c] Cold-smoked salmon.
[d] Cold-smoked trout.
[e] Information on the prevalence of *L. monocytogenes* in specific products was not available.

TABLE 3. *Prevalence of* Listeria monocytogenes *in ready-to-eat dairy products*

Product	Country	Source	Prevalence[a]	Reference
Cheeses				
Hard and semihard	England, Wales	Retail outlets	1/66 (1.5%)	*106*
	Portugal	Markets, supermarkets	8/34 (24.0%; wrapped)	*107*
Soft	England, Wales	Retail outlets	63/769 (8.2%; ripened) 4/366 (1.1%; unripened)	*106*
	Norway	Retail stores	10/90 (11.0%)[b]	*220*
	Sweden	Supermarkets, delicatessens	13/31 (42.0%; raw milk) 7/302 (2.0%; heat-treated milk)	*154*
	Italy	Shops, supermarkets	8/164 (4.9%)	*208*
	Brazil	Retail stores	11/103 (10.7%)	*57*
	Chile	Industries, markets, restaurants, hospitals	2/256 (0.8%)	*51*
	United States	Retail markets	5/2,931 (0.2%)	*99*
	Turkey	Retail stores, supermarkets	6/120 (5.0%)	*2*
	Portugal	Retailers, producers	2/50 (4.0%)	*177*
	Spain	Supermarkets	1/99 (1.0%)	*262*
Various cheeses[c]	England, Wales	Retail outlets	1/141 (0.7%; ewe's milk) 22/476 (4.6%; goat's milk)	*106*
	Belgium	Various sales outlets	2/71 (2.8%)	*60*
	Cyprus	Production sites, retail outlets	21.0%	*73*
	Italy	Plants, supermarkets, food markets	88/505 (17.4%)	*92*
	United States	Retail markets	23/1,623 (1.4%; blue veined) 14/1,347 (1.0%; mold ripened)	*99*
	Portugal	Retailers, producers	6/371 (1.6%)	*177*
	Belgium	Retail market	7/15 (46.7%; raw milk, not prepackaged) 6/10 (60.0%; pasteurized milk, not prepackaged)	*259*
	Italy	Retail, plants	148/13,858 (1.1%)	*34*
Cream	England, Wales	Retail outlets	2/48 (4.2%)	*106*
	Hungary	Food stores, restaurants, caterers	1/4 (25.0%; whipped cream)	*139*
Ice cream	England, Wales	Retail outlets	3/150 (2.0%)	*106*
	Hungary	Food stores, restaurants, caterers	1/15 (6.6%)	*139*
	Korea	Supermarkets, quarantine stations	8/132 (6.1%)	*17*
	India	Retail markets	1/15 (6.7%; open, not packaged)	*266*
	Chile	Industries, markets, restaurants, hospitals	21/603 (3.5%) 5/68 (7.4%; individually served) 16/535 (3.0%; prepackaged)	*51*
	Italy	Retail, plants	5/1,734 (0.3%)	*34*
Milk				
Pasteurized	England, Wales	Retail outlets	11/1,039 (1.1%)	*106*
	United States	Retail outlets	1/5,519 (0.018%)	*89*
Raw	Portugal	Retailers, producers	1/6 (16.7%)	*177*
	Korea	Supermarkets, quarantine stations	2/45 (4.4%)	*17*
Yogurt	England, Wales	Retail outlets	4/180 (2.2%)	*106*

[a] Number of positive samples/number of samples tested (% positive samples).
[b] Majority of samples were cut at the stores, and the remainder were unopened, prepackaged portions.
[c] Cheese type was not available or *L. monocytogenes* prevalence referred to various types of cheeses.

precut wedges in a retail survey of soft and semisoft cheeses in Sweden. Prevalence differences associated with the type of retail outlet also have been documented; soft cheeses in supermarkets yielded more *L. monocytogenes*–positive samples than did products from small shops *(208).*

Produce. Produce-associated outbreaks have been reviewed by the U.S. National Advisory Committee on Microbiological Criteria for Foods (NACMCF) in a document developed to provide recommendations for the control of microbial hazards in whole and processed produce *(189).* Raw celery, tomatoes, and lettuce were suspected to be linked to cases of listeriosis among patients in eight Boston hospitals in 1979 *(114),* and contaminated coleslaw was identified as the food vehicle for a listeriosis outbreak in Canada in 1981, which provided the first documentation of foodborne transmission of *L. monocytogenes (234).* Given

TABLE 4. *Prevalence of* Listeria monocytogenes *in produce*

Product	Country	Source	Prevalence[a]	Reference
Dried fruits	Portugal	Retailers, producers	1/12 (8.3%)[b]	*177*
Field cress	United States	Supermarkets	2/11 (18.2%)	*247*
Frozen vegetables	Portugal	Retailers, producers	35/271 (12.9%)	*177*
Lettuce	Australia	Supermarkets	1/60 (1.7%)[c]	*246*
	Spain	Restaurants	1/10 (10.0%; raw) 1/10 (10.0%; ready to eat)	*243*
	Norway	Markets	1/200 (0.5%)	*130*
	Ireland	Supermarket	1/80 (1.3%; iceberg)[c] 4/80 (5.0%; romaine)[c] 3/80 (3.8%; radicchio)[c]	*88*
Mushrooms	Norway	Markets	1/156 (0.6%)	*130*
	United States	Retail stores	1/100 (1.0%)[d]	*229*
Potatoes	United States	Farmers' markets	4/8 (50.0%)	*247*
Sprouts				
Alfalfa sprouts	United States	Grocery stores	1/206 (0.5%)	*245*
Bean sprouts	Ireland	Supermarket	1/80 (1.3%)[c]	*88*
Strawberries	Norway	Markets	1/173 (0.6%)	*130*
Vegetables[e]	Canada	Hospital food service departments	5/135 (3.7%)[f]	*198*
	Italy	Plants, supermarkets, food markets	33/738 (4.5%)	*92*
	United Kingdom	Catering and retail premises	88/2,934 (3.0%; open)[g]	*225*
	United Kingdom	Supermarkets, shops, greengrocers	90/3,849 (2.3%; bagged)[g]	*226*
	Ireland	Supermarket	2/80 (2.5%)	*88*
Vegetable salads	Singapore	Restaurants, supermarkets, manufacturers	2/50 (4.0%)[h]	*191*
	United States	Restaurants, supermarkets	1/63 (1.6%)[i]	*146*
	England, Wales	Retail premises	77/2,276 (3.0%)[c]	*152*
	Cyprus	Production sites, retail outlets	24.0%	*73*
	United States	Retail markets	22/2,966 (0.7%)[c]	*99*
	Ireland	Supermarket	10/80 (12.5%)[j]	*88*

[a] Number of positive samples/number of samples tested (% positive samples).
[b] Walnut, hazelnut, pine nut, sultana, and apricot.
[c] Prepackaged.
[d] Prepackaged or loose.
[e] Various products or vegetable category not specified.
[f] Packaged salad mix, coleslaw mix, cauliflower florets, and sliced green peppers tested after 7 days of storage in hospital coolers (5°C).
[g] Single or mixed salad vegetables.
[h] Positive samples contained cucumber, carrot, potato, cabbage, and salad dressing.
[i] Positive sample contained iceberg lettuce, red cabbage, carrots, cucumbers, and tomatoes.
[j] Dry coleslaw mix.

the ubiquitous nature of *L. monocytogenes,* its transmission via produce is not surprising, and consumer exposure to low levels of the pathogen via raw and minimally processed vegetables may be inevitable *(21).*

Outbreak investigations have illustrated that determination of a single point of contamination of produce in the production chain is difficult *(189).* Soil appears to be the primary reservoir of microbial contaminants for fruits and vegetables at the preharvest level, and inappropriate agricultural practices (e.g., irrigation using contaminated water or fertilization with uncomposted manure) may contribute to the transmission of pathogens to fresh produce *(22, 162, 192).* Animals may serve as an additional source of contamination during primary production, and humans may contribute to contamination of produce both at the preharvest and the retail and food service levels *(22, 110, 146).*

Because of increased consumption of fresh produce (unprocessed or minimally processed) during the last three decades, either in settings outside the home or as precut, washed, and bagged RTE salads, the risk of produce-associated pathogen transmission also has increased *(21, 189).* Because minimal processing of fruits and vegetables may not assure microbial safety of these products, the possible presence of psychrotrophic pathogens, especially *L. monocytogenes,* raises concerns *(192).* Growth of *L. monocytogenes* during refrigerated storage has been demonstrated in various types of produce, including asparagus, broccoli, cauliflower, chicory endive, and lettuce *(22).* High levels of the organism in vegetables are not necessarily associated with unacceptable product quality *(244),* and highly contaminated produce may not appear spoiled.

Numerous surveys have assessed the prevalence of *L. monocytogenes* in fresh produce, and investigations undertaken during the 1980s and the first half of the 1990s were reviewed by Beuchat *(22)*. The incidence of the pathogen in produce in retail and food service environments as reported in more recent studies is presented in Table 4. Because fruits and vegetables are commonly consumed raw, the terms ''ready to eat'' or ''ready to use'' are vague regarding produce as compared with other foods. Therefore, information on the presence of *L. monocytogenes* in both unprocessed and minimally processed produce is presented here. In a survey of food samples obtained from restaurants in Spain between 1999 and 2000, the incidence of *L. monocytogenes* was equal in raw and RTE lettuce *(243)*. Mena et al. *(177)* collected samples of several types of foods from producers and retailers in Portugal in 2000 and 2001 and reported contamination rates in frozen vegetables ranging from 14.8 to 22.6%. Although such products are generally considered to be of lower risk than RTE produce, food handling instructions on the label must make clear to consumers that proper preparation is required before consumption. Parameters such as season, type of product, and outlet (e.g., location, supplier, production, or display attributes) have not been found to have a clear association with *Listeria* spp. contamination or the microbiological quality of vegetables *(224, 225, 245)*.

Failure to detect *L. monocytogenes* has been documented in many studies at retail and food service establishments from which samples of raw and RTE produce have been examined, including broccoli, cabbage, carrots, cauliflower, celery, corn, cucumber, herbs, lettuce, melon, mixed vegetables for salad or soup, mushrooms, peppers, pickled vegetables, potatoes, radishes, spinach, sprouts, tomatoes, watercress, watermelon, and RTE salads such as potato salad, coleslaw, and fruit salad *(54, 84, 88, 98, 107, 112, 121, 134, 139, 150, 205, 223, 224, 229, 231, 243, 245)*. In addition to an association with agricultural and manufacturing practices, presence or absence of the pathogen in fruits and vegetables may be associated with the type of plant (extent of contact with soil), the location of contamination (external or internal in plant tissues), the natural microflora present in different types of produce *(130)*, and the extent of surveys for each type of product.

L. MONOCYTOGENES SUBTYPES

The differentiation of *L. monocytogenes* isolates with phenotypic or molecular subtyping methods has provided useful information relative to the phylogeny, epidemiology, and ecology of the organism, and this information can be utilized to assess the distribution and transmission of the pathogen in various segments of the food chain (*232, 268)*. *L. monocytogenes* serotype 4b strains tend to predominate among human clinical isolates, whereas food isolates are mainly of serogroup 1/2 *(17, 51, 92, 107, 126, 154, 155, 194, 262)*. Predominance of serotype 1/2a and 1/2b isolates has been demonstrated in retail surveys of various RTE foods (meat products, seafood, dairy products, and produce), followed by 1/2c or 4b isolates, whereas serotype 3b strains have been isolated less frequently *(1, 27, 57, 62, 94, 106, 108, 112, 121, 131, 227, 259)*. According to Johansson et al. *(131)*, 86% of the strains isolated from RTE vacuum-packaged fish products at retail outlets in Finland during 1996 belonged to serotype 1/2a, a serotype that was increasingly associated with human listeriosis in Finland during an 11-year (1990 through 2001) study period *(157)*. However, contamination of RTE foods by multiple serotypes or predominance of serotype 4b has been observed in some cases *(61, 107, 186)*. Product- and geography-specific distributions of serotypes also have been demonstrated *(17, 51, 92, 262, 271)*.

Because the vast majority of human infections are caused by *L. monocytogenes* strains belonging to serotypes 4b, 1/2a, and 1/2b *(171, 236)*, use of serotyping as the sole subtyping method is of limited value in the assessment of the contribution of retail and food service environments to human listeriosis. Use of phage typing in conjunction with serotyping increases considerably the discriminatory power of serotyping and can be particularly valuable for detecting contamination of foods with multiple *L. monocytogenes* strains *(51, 107)*. However, drawbacks of phage typing include experimental and biological variability, and large numbers of strains are nontypeable *(51, 77, 78, 268)*. The development of highly sensitive and reproducible DNA-based subtyping methods, such as ribotyping and pulsed-field gel electrophoresis (PFGE), has provided solutions to the above limitations of conventional and phenotypic methods *(268)*.

Molecular subtyping methods exploited in recent investigations have provided a better insight into the role of retail environments in contamination of RTE foods with *L. monocytogenes* and potential associations among various isolates of the pathogen. With random amplified polymorphic DNA (RAPD) analysis of *L. monocytogenes* isolates recovered from cooked meat products (sliced and packaged by retailers just before sale) and vacuum-packaged smoked salmon (packaged before distribution) from retail outlets in Spain, various RAPD types were found among strains from cooked meat products, but a single RAPD type was recovered from all positive samples of smoked salmon *(1)*. In that study, 56% of the meat isolates were recovered from products handled by 5 of the 55 retailers from which samples were taken, and characterization of these isolates indicated a predominance of certain RAPD types at certain retailers.

Recent molecular subtyping data revealed the ability of *L. monocytogenes* to establish persistent contamination in retail environments *(233)*, in concert with similar findings in food-processing establishments *(135, 175, 180, 197, 238)*. Sauders et al. *(233)* characterized food and environmental *L. monocytogenes* isolates from retail establishments in New York State using ribotyping and allelic variation of the virulence gene *hly*. For 16 of 50 establishments with *L. monocytogenes*–positive samples, identical ribotypes were isolated from food and/or environmental samples on different dates, and 42 of 98 *L. monocytogenes*–positive food samples were contaminated with ribotypes that persisted in the respective establishment. Because some of the persistent ribotypes also have been associated with cases of human listeriosis, it is evident that some of the ribotypes that can persist in retail environments also may cause human illness. A certain ribotype that was identified as the epidemic clone in two outbreaks in the United States *(37, 40)* was found in the above study to persist in two retail premises.

Clustering of *L. monocytogenes* isolates from retail RTE foods in Belgium into distinct molecular groups using repetitive element sequence-based PCR revealed that cross-contamination of foods with the pathogen occurred at both the production plant and retail markets *(259).* Cross-contamination most likely was due to the introduction of persistent strains via contaminated raw or unpackaged materials or products. In the same study, cheese isolates from a certain retail market were clustered in three molecular groups, indicating the presence and rotation of various strains in that particular market and potential contamination of the products at the manufacturing level. Gray et al. *(103)* characterized isolates from RTE foods sampled from retail markets in Maryland and northern California *(99)* and concurrent human isolates using ribotyping and PCR restriction fragment length polymorphism analysis of the virulence gene *hly.* Based on lineage, ribotype, and *hly* type distributions and in vitro cytopathogenicity results, these researchers concluded that human and food isolates represented distinct but overlapping populations. Similar findings were reported by Gilbreth et al. *(94)* in a follow-up study based on PFGE and serotyping, which indicated that clinical isolates represented a heterogeneous group and that only 31% of the pulsotypes obtained were also present in food samples.

Product-specific distributions of *L. monocytogenes* molecular subtypes have been reported in some cases *(94, 103, 233).* However, the presence of common lineages, pulsotypes, or ribotypes in various food categories and wide genetic diversity of strains recovered from foods also have been observed *(45, 108, 193).* Hence, identification of a clear association of pathogen subgroups with potential sources of contamination, RTE foods, and/or clinical isolates may not be feasible in some cases. One hypothesis is that retail establishments serve as reservoirs of multiple subtypes of the pathogen. In a survey of RTE raw seafood collected from retail stores in Japan, the isolation of different ribotypes of the organism from foods collected from the same store at two sampling times demonstrated that repeat, albeit multiple-source, contamination of RTE foods in certain retail premises is likely *(108).*

Retail food survey enumeration data *(99)* and molecular subtyping data *(103)* were utilized in a subtype-specific dose-response analysis that revealed that the dose-response relationship for *L. monocytogenes* in humans may depend on ribotype or genotypic lineage of strains of the pathogen *(45)*; the average dose among ribotypes varied by more than 5 log units, and lineage II isolates were present at higher concentrations in foods than were lineage I isolates. Thus, the researchers concluded that both the exposure concentration and the subtype of the organism should be taken into account in risk assessments. The existing hypothesis of variation in foodborne transmission potential and virulence among strains of *L. monocytogenes* is now also supported by molecular evidence *(45, 103, 233).* Therefore, use of the newer molecular techniques should lead to improved risk assessment and management approaches, which should ensure more effective control of this pathogen throughout the food chain.

CONTAMINATION LEVELS

Different criteria with respect to tolerable levels of *L. monocytogenes* in RTE foods have been established in various countries *(102, 195).* A zero-tolerance policy (i.e., absence of the pathogen in two 25-g samples of foods) has been established by regulatory agencies in the United States, whereas in most European countries the regulatory limit is <100 cells per g at the time of consumption. In some countries (e.g., Canada and Denmark) both of the above stances are adopted, with zero tolerance embraced for only some foods. However, the attainability of complete absence of *L. monocytogenes* in certain RTE foods has been questioned, as has the positive impact of a zero-tolerance policy on public health *(46, 195).* Epidemiological data worldwide indicate that *L. monocytogenes* concentrations not higher than 100 cells per g of food at the time of consumption pose a low risk to consumers *(122, 195).* Foods linked to cases of listeriosis usually are contaminated with more than 1,000 cells per g *(79).*

The need for development of international microbiological criteria for *L. monocytogenes* in foods and the value of microbial risk assessment approaches have been acknowledged *(195).* Risk assessment data indicate that levels of *L. monocytogenes* consumed play an important role in the incidence of listeriosis and that concentration of the organism in RTE foods is more critical than just its presence, suggesting that risk management efforts should focus on foods that support proliferation of the organism to high levels *(46, 123, 195, 215).* Despite the fact that strain virulence constitutes one of the parameters that appear to affect the infectious dose of *L. monocytogenes,* all strains of the organism are currently considered potentially pathogenic from a food safety perspective *(173).* However, contamination of RTE foods with strains that share common phenotypic *(61)* or molecular *(233)* typing characteristics with isolates linked to human infections is obviously of higher concern.

According to the revised guidelines for the microbiological quality of some RTE foods sampled at the point of sale (developed by the Public Health Laboratory Service in the United Kingdom), RTE foods containing any serogroup of *L. monocytogenes* at levels ≥100 CFU/g at the time of sale are considered unacceptable or potentially hazardous *(93).* In retail and food service surveys where quantitative determinations of *L. monocytogenes* were carried out, detectable levels of the pathogen in RTE foods in most cases were low (<100 CFU/g or even <10 CFU/g) *(7, 66, 81, 88, 99, 143, 186, 196, 231, 240, 258, 259, 269).* However, concentrations at or above 100 CFU/g also have been reported in deli salads, meat and poultry products such as corned beef, luncheon meats, and pâté, seafood, soft cheeses, and vegetables (Table 5).

Higher concentrations of *L. monocytogenes* generally have been reported for certain product categories. For example, among RTE seafood products, levels exceeding 100 CFU/g have been found primarily in smoked and gravad

TABLE 5. Listeria monocytogenes *contamination (≥100 CFU/g) detected in various ready-to-eat products*

Product	Country	*L. monocytogenes* concn (CFU/g)[a]	Reference
Deli salads	United States	$>10^3$–10^4 (1/202)	*99*
Meat and poultry			
Corned beef	Australia	~3 × 10^4 (2/50)	*101*
Ham	United Kingdom	3.4 × 10^4	*74*
Luncheon meats	United States	$>10^2$–10^3 (7/82)	*99*
		$>10^3$–10^4 (1/82)	
Minced meat	Belgium	3 × 10^2	*259*
Pâté	Wales	$>10^2$–10^3 (7/69)	*186*
		$>10^3$–10^4 (4/69)	
		$>10^4$ (10/69)	
	Northern Ireland	$>10^4$	*269*
	England, Wales	2 × 10^2–10^3 (1/36, meat based; 2/17, poultry based)	*193*
		10^3–10^4 (2/36, meat based; 1/17, poultry based)	
		10^4–10^5 (2/36, meat based; 2/17, poultry based)	
		10^5–10^6 (1/17; poultry based)	
		$\geq 10^6$ (2/36; meat based)	
	Spain	10^2–10^3 (1/6)	*66*
	New Zealand	1.7 × 10^3	*271*
Turkey products	Northern Ireland	$>10^4$	*269*
Seafood			
Seafood pâté	England, Wales	2 × 10^2–10^3 (2/8)	*193*
Seafood salads	United States	$>10^2$–10^3 (2/115)	*99*
Smoked seafood	Spain	10^2–10^3 (4/12, opened salmon; 9/16, vacuum-packaged salmon; 5/10, vacuum-packaged trout)	*66*
		10^3–10^4 (1/16, vacuum-packaged salmon; 1/10, vacuum-packaged trout)	
	United States	$>10^2$–10^3 (6/114)	*99*
		$>10^3$–10^4 (1/114)	
		$>10^5$–10^6 (2/114)	
	Belgium	$>10^3$–10^4	*259*
Soft cheeses	England, Wales	$>10^3$ (13/63)	*106*
	Norway	$>10^3$ (4/10)	*220*
Vegetables and salads	England, Wales	$>10^2$–$<10^3$ (1/77)	*152*
	Spain	10^2–10^3 (1/14)	*61*
		$>10^3$ (3/14)	
	United States	$>10^2$–10^3 (1/22)	*99*
	United Kingdom	10^2–$<10^3$ (1/88)	*225*
	United Kingdom	10^2–$<10^3$ (1/90)	*226*
	Ireland	1.2 × 10^3 (1/10)	*88*

[a] Numbers in parentheses are the number of samples (when available) at the respective contamination level/the total number of positive samples in which *L. monocytogenes* concentration was determined.

fish and smoked seafood *(99, 131, 155, 259)*. Dominguez et al. *(66)* reported that 18 of the 38 samples of retail smoked fish that were positive for *L. monocytogenes* contained the organism at levels between 100 and 1,000 CFU/g, and two samples (vacuum-packaged cold-smoked salmon and rainbow trout) were contaminated with concentrations higher than 1,000 CFU/g (1,100 and 1,700 CFU/g, respectively). Pâtés can be contaminated with levels of the organism exceeding 10^4 CFU/g, and concentrations as high as or higher than 10^6 CFU/g also have been documented *(186, 193, 269)*.

Conflicting data have been reported regarding contamination levels in prepackaged compared with in-store–packaged RTE products. Morris and Ribeiro *(186)* reported that of the 10 pâté samples yielding *L. monocytogenes* counts higher than 10^4 CFU/g during a survey in Wales in 1989, 9 were samples displayed in delicatessen counters (slices cut from bowls or loaves) and only 1 was from an unopened refrigerated package of pâté. According to Nichols et al. *(193),* during sampling of pâté products at the point of retail sale in England and Wales in 1994, significantly more opened samples contained *L. monocytogenes* at levels ≥200 CFU/g than did prepackaged samples. In agreement with the above observations, a survey undertaken in retail outlets and supermarkets in Spain in 2000 indicated that only an opened pâté sample was contaminated with the pathogen at concentrations higher than 100 CFU/g, whereas all *L. monocytogenes*–positive prepackaged samples contained less than 100 CFU/g *(66)*. In contrast, in a survey of the incidence and levels of *L. monocytogenes* among eight categories of RTE foods sampled from retail markets in California and Maryland during 2000 and 2001, Gombas et al. *(99)* reported that concentrations of the pathogen tended to be higher in manufacturer-packaged products than in in-store–packaged products: of the 21 samples of RTE foods that contained the pathogen at levels higher than 100 CFU/g, 16 were manufacturer packaged. However, these investigators acknowledged that the impact of packaging location on contamination levels of *L. monocytogenes* requires further research.

The different trends in contamination prevalence and levels observed by various investigators most likely reflect corresponding differences in the control measures implemented in different countries. Assuming that the likelihood of postlethality treatment contamination of RTE foods with low levels of *L. monocytogenes* is similar at the production and retail and food service levels, high pathogen concentrations in prepackaged products (which indicates contamination at the production level) would be due to pathogen growth during distribution and storage, as favored by the extended shelf life of such products compared with that of products handled at retail and food service operations *(196)*. High concentration of the organism in manufacturer-packaged products may result in cross-contamination of other RTE foods at the retail and food service level when such foods are opened and handled (e.g., sliced) using common utensils *(147, 263)*. However, given the complexity of retail and food service operations, control efforts may be more challenging to apply at these establishments than at food processing plants. Thus, higher *L. monocytogenes* prevalence may be found in RTE foods handled by retail and food service workers, whereas in-plant–packaged products may have higher levels of the pathogen when these products are purchased by the consumer. However, RTE products handled by retail and food service workers also may be contaminated with high concentrations of the pathogen when adequate cleaning, sanitation, and hygiene programs are not in place. Inappropriate temperature controls in retail and food service operations may result in high levels of the organism regardless of the point of contamination.

In a recent consumer phase risk assessment conducted to identify high-risk consumer food handling practices for deli meats and to evaluate the relative risk of listeriosis associated with these practices, the level of *L. monocytogenes* contamination at retail was identified as the input parameter with the highest association with mortality *(274)*. Thus, to assess consumer vulnerability to foodborne listeriosis and develop effective control measures, surveys must provide information on the levels of the pathogen in various RTE foods, both prepackaged and in-store packaged, and on the impact of food handling practices applied at retail and food service establishments and in homes.

TRANSMISSION OF *L. MONOCYTOGENES* IN RETAIL AND FOOD SERVICE ENVIRONMENTS

Potential sources of *L. monocytogenes* contamination of foods in retail and food service operations include incoming products, food handlers, customers, and environmental sources; the last category includes utensils and equipment, which under conditions of poor cleaning and sanitation may harbor pathogenic microorganisms or serve as vehicles of cross-contamination *(30, 31, 251)*. Knowledge of potential sources and routes of contamination of RTE foods with *L. monocytogenes* can be useful in the development of effective control measures throughout the food system. Information on the transmission potential of the pathogen within retail and food service environments is provided by epidemiological and surveillance investigations and microbiological food survey data.

Epidemiological and surveillance investigations. The potential association of retail and food service environments with foodborne disease events caused by viral and bacterial agents has been demonstrated by surveillance and epidemiological data *(30, 49, 52, 56, 111, 115, 172, 251)*. In a case-control study undertaken to assess the role of food in sporadic cases of listeriosis in a multistate population between 1988 and 1990, the findings demonstrated that delicatessen counters may serve as a source of *L. monocytogenes (235)*. The analysis indicated that 17% of sporadic listeriosis cases could be linked to consumption of food from a store delicatessen counter, and listeriosis patients were more likely to have consumed foods from delicatessen counters than were controls *(235)*. Sliced meats and block cheese purchased from delicatessen counters also were among the foods from patients' refrigerators that yielded isolates of the same enzyme type as the clinical isolates, as determined in a complementary microbiological investigation *(207)*.

The investigation of a large listeriosis outbreak involving 279 cases in 1992 in France revealed that contaminated pork tongue in aspic was the major vehicle of human infection *(125)*. However, the isolation of the epidemic strain from various delicatessen products handled in the same retail stands where the pork tongue was sold and from utensils used in these environments indicated that cross-contamination of foods in delicatessen counters may have contributed to the magnitude of that particular outbreak *(18, 125)*. Cross-contamination of various foods from contaminated pork tongue in aspic via the use of shared knives also was associated with a listeriosis outbreak in France in 1999 and 2000 *(67)*.

Foodborne listeriosis cases linked to foods prepared at catering establishments also have been reported. Numerous cases of febrile gastrointestinal listeriosis among students and staff of two schools in Italy in 1997 were linked to consumption of corn salad served at the schools' cafeterias by the same caterer; because sterile canned corn was used in the salad, cross-contamination probably occurred on the catering premises during handling and preparation *(13)*. Sandwiches prepared and supplied by a single caterer to retail outlets in two hospitals in England were identified as the food vehicle of a listeriosis outbreak in 1999 that affected two immunocompromised and two elderly patients and resulted in the death of one of these patients *(10)*.

Microbiological food survey data. In addition to the information provided by epidemiological investigations, the role of retail and food service environments in the transmission of *L. monocytogenes* has been demonstrated by observations recorded during food surveys assessing the incidence of the pathogen in various RTE foods. Sampling and analysis of soft cheeses from retail stores in Norway revealed that 7 of 10 *L. monocytogenes*–positive samples were cut in the same store. Because these samples were contaminated with strains of the same serotype and the contamination levels were generally low, the most likely source of the pathogen was the retail store *(220)*. Similarly, Akpolat et al. *(2)* reported that of six samples of soft cheese that were positive for *L. monocytogenes* in retail stores and supermarkets in Turkey, four were cut in the same store. According to Kiss et al. *(139)*, the isolation of *Listeria* spp. from sweet products and buffet meals prepared from different raw materials and collected from the same buffet at the same time was indicative of poor hygienic conditions. In another survey, the presence of *Escherichia coli* and to a lesser extent *L. monocytogenes* in vegetable salads served at restaurants and supermarkets was attributed to contamination during handling of the salads; all contaminated samples were obtained from only 5 of 31 food service establishments surveyed, and 4 of these establishments served contaminated salads at two different times *(146)*.

In a survey undertaken in New Zealand, RTE muscle foods (i.e., meat, poultry, and seafood) bought from delicatessens in retail markets were more frequently contaminated with *Aeromonas, Yersinia enterocolitica,* and *L. innocua* than were similar prepackaged products. The trend for *L. monocytogenes* was reversed, but it was assumed that the high prevalence of the pathogen in vacuum-packaged smoked salmon samples was the most likely reason for this observation *(117)*. According to Sheridan et al. *(240)*, at Irish retail outlets *Listeria* spp. were found only in open RTE meats (i.e., ham, turkey, roast beef, and roast pork) and were not detected in prepackaged (vacuum- or gas-packaged) products. Similar observations were made by Nichols et al. *(193)*, who reported significantly higher *L. monocytogenes* prevalence in pâtés that were open (3.8%) than in prepackaged products (1.2%) sampled from retail outlets in the United Kingdom. In a 2-year survey of RTE meat products in supermarkets in Belgium, higher incidence rates of *L. monocytogenes* were obtained for whole cooked meat products after slicing (6.65%) than before slicing (1.56%), indicating recontamination of the products at the retail level *(258)*.

Repeat contamination of RTE foods at certain retail premises or higher contamination rates in open than in prepackaged products also have been reported by other investigators *(66, 99, 108, 262, 266)*. Data collected for RTE foods from retail markets in the United States in 2000 and 2001 indicated that the prevalence of *L. monocytogenes* in in-store–packaged deli salads, luncheon meats, and seafood salads was 3.6, 2.7, and 6.9%, respectively, whereas the corresponding prevalence in manufacturer-packaged products was 1.4, 0.4, and 1.4%, respectively *(99)*. Potential reasons for these findings include additional handling of food products at retail stores or inappropriate refrigeration temperatures in the retail deli cases in which in-store–packaged products were held. However, high *L. monocytogenes* contamination rates also have been documented for prepackaged RTE products *(66, 186, 267)*. Higher incidence of *L. monocytogenes* was observed in prepackaged ham (16.7%) than in product that was freshly-cut at the point of sale (1.4%) in supermarkets and other shops in Greece *(267)*.

Contamination routes. Some researchers have suggested that establishment of microbiological criteria for retail foods should be based on knowledge of retail systems and on conditions associated with handling and use of such products *(209)*. As indicated by previously discussed food survey data *(258)* and by environmental sampling data from retail premises *(151)*, slicing is one of the handling activities that may contribute considerably to pathogen transmission in retail handled RTE meat and poultry products. Humphrey and Worthington *(118)* reported isolation of *L. monocytogenes* from 13% of slicer blades sampled in butcher shops in the United Kingdom between 1989 and 1990. In another investigation, the pathogen was recovered from a slicer and a knife from a supermarket delicatessen in New Zealand *(116)*. Isolation of *L. monocytogenes* from utensils that come into direct contact with foods intended to be consumed without further cooking indicates the high likelihood of such utensils serving as a source of contamination or cross-contamination of RTE foods when proper food handling practices and adequate cleaning and sanitation procedures are not in place. According to Hudson and Mott *(116)*, slicing machines may become contaminated with the pathogen from the outside of luncheon meat packages that are not removed and can then cross-contaminate delicatessen products during slicing.

The association of slicing equipment with transmission of *L. monocytogenes* in retail and food service environments is suggested by the ability of the organism to adhere to surfaces and form biofilms on various materials used in food-processing facilities *(20, 26, 158)*. Lin et al. *(147)* assessed the transfer dynamics of *L. monocytogenes* to RTE meat and poultry products from a commercial slicer artificially contaminated with the pathogen and concluded that the extent of contamination of deli meats depended on the initial levels of the pathogen on the slicer blade and on the type of product. According to that study, higher inoculation levels on the slicer blade resulted in more *L. monocytogenes*–positive samples of sliced deli meats. In addition, more positive samples were obtained from oven-roasted turkey than from beef bologna containing potassium lactate and sodium diacetate or from salami. The number of positive samples and the levels of *L. monocytogenes* appeared to increase during refrigerated (4°C) storage in turkey and to decrease in bologna and salami *(147)*. Thus, the health risk associated with cross-contamination of deli meats during slicing appears to be product dependent; products of high risk are those that allow higher transfer of *L. monocytogenes* and constitute a more favorable growth substrate for the organism *(24, 33, 97)*. However, slicing equipment may play an important role in the transmission of the pathogen even when low-risk products are sliced. Vorst et al.

(263) reported that slicing of salami, a product that does not support growth of *L. monocytogenes,* resulted in the formation of a fat layer on the slicer blade, which may facilitate a prolonged transfer of the pathogen during slicing. Thus, contaminated salami may serve as a vehicle of cross-contamination during slicing of other RTE products. If these subsequently sliced products support growth of the pathogen during retail, food service, or home storage, then there is a possibility of consumer exposure to potentially hazardous levels of the organism.

L. monocytogenes was isolated from 1.7% of retail refrigerators and from 0.9% of refrigerator handles sampled in food stores in Greece; the positive samples recovered from refrigerators corresponded to surfaces in contact with cheese, sausages, and miscellaneous products *(239).* However, the pathogen was not isolated from cold storage rooms in cafeterias in France, and only *L. innocua* and *L. seeligeri* were recovered from a vegetable cold storage room and from both the vegetable and meat compartments of a refrigerator, respectively *(63).* The low incidence of *L. monocytogenes* in retail and food service refrigerators in these studies is in agreement with similar findings for domestic refrigerators *(16, 25, 53, 124, 239)* and has been attributed to limited growth of the organism under the low relative humidity conditions in refrigerator environments, sublethal injury of cells under those conditions, and firm attachment and thus reduced recovery of organisms from surfaces *(53, 124).* However, even if *L. monocytogenes* is only a transient contaminant, the potential for cross-contamination of RTE products via contaminated refrigerator surfaces should be acknowledged.

Bacterial transfer between surfaces used in food preparation is highly variable *(44, 182, 184).* Nevertheless, investigation of bacterial survival and transfer under laboratory conditions has revealed that contact of fingers or food contact surfaces with contaminated cloths or surfaces, even when the contamination level is low, may result in pathogen transfer sufficient to pose a health hazard *(237). L. monocytogenes* can survive and persist on experimentally inoculated fingertips, particularly in the presence of food residues (i.e., milk), and hand washing may not be sufficient to eliminate the pathogen when it is present at high levels *(137, 241).* The use of gloves during food handling and preparation may reduce bacterial transfer from food to the hands of food service workers and from their hands to other foods *(182).* However, both proper hand washing and glove use are required if the risk of cross-contamination is to be reduced *(44, 183, 202, 204).* A high microbial load, including the pathogen *Staphylococcus aureus,* found on apron cloths used in butcher shops selling both raw and cooked or RTE products indicated that the apron cloths may serve as vehicles of cross-contamination of food contact surfaces and consequently foods when used repeatedly *(151).*

The important role of food workers and their food handling practices in foodborne pathogen transmission has been recognized. Ill food handlers or asymptomatic carriers of pathogens have been identified as the source of infection in numerous foodborne outbreaks *(111, 156, 176, 189, 251).* Presence of pathogens on hands of food workers and the potential for pathogen transfer to foods during handling has been demonstrated *(6).* Higher prevalence of *Listeria* spp. on the hands of food workers than of clerical workers and hand carriage of *L. monocytogenes* by delicatessen workers have been documented *(137).* Kerr et al. *(138)* reported that a predominant *L. monocytogenes* RAPD type was isolated from the hands of three workers in the same delicatessen; according to these investigators, this finding may indicate either predominance of certain strains in retail establishments or that certain strains are better adapted than others to survival on hands. Therefore, food handlers may play a critical role in the transmission of *L. monocytogenes* in retail and food service environments, either as the primary source of the pathogen or by mediating pathogen transfer from contaminated surfaces, utensils, or foods to pathogen-free RTE products. This observation may be particularly important for products such as sandwiches, which require extensive handling and use of various ingredients for their preparation. Sandwiches may be of low microbiological quality, especially under conditions of inadequate temperature control, and have been linked to several outbreaks of foodborne illness *(10, 56, 58, 119, 251, 270).*

The majority of reported cases of foodborne illness in the United States have been associated with poor food handling practices *(39).* Investigations in which food handling practices on retail and food service premises were recorded provide information that can be utilized in assessing potential contamination routes and determining problem areas in these operations. Observed food handling practices that may result in cross-contamination of RTE foods include inadequate hand washing *(47, 104, 105, 253),* touching unwrapped raw food without clean protective gloves *(8),* handling uncovered salad vegetables with bare hands or with a common serving utensil *(225),* using common weighing balances for RTE foods and other items, wrapping and handling various products in common areas, using the same counters to serve both raw and cooked or RTE meats, and handling unwrapped RTE meats after handling raw meats without washing hands *(151).* Food worker practices such as wearing the same gloves for extended periods of time and washing hands less frequently when wearing gloves than when handling foods with bare hands also have been observed *(105, 161).*

In conjunction with the findings of observational studies, investigations embracing risk assessment approaches can contribute to the evaluation of the risk involved in certain food handling practices, both at the retail level and in the home *(204, 274).* Identification of practices that may compromise food safety can be useful for food handler education, which can provide the foundation for constructive changes and improvements in sanitary and hygienic food handling. Pérez-Rodríguez et al. *(204)* used an approach integrating risk assessment methodologies and food safety objectives (i.e., *L. monocytogenes* levels of 100 CFU/g at consumption) and concluded that using the same gloves to handle raw minced chicken meat contaminated with *L. monocytogenes* and then to handle cooked ham slices was the cross-contamination scenario of the highest risk. These investigators also reported that hand washing followed by bare-hand contact with food may not be adequate to ensure food safety if subsequent home storage conditions (i.e., temperature and time) favor proliferation of the pathogen.

In a recent survey of butter samples from catering premises in the United Kingdom, *Listeria* spp. were recovered more often from butter that was uncovered, had visible food material (e.g., crumbs), or was spread using a shared utensil *(143),* and butter softened at catering premises was more likely to be contaminated with *Listeria* spp., including *L. monocytogenes.* This contamination may be the result of additional handling by the caterers, which increased the opportunity for cross-contamination (*143).* Unsatisfactory or unacceptable microbiological quality of RTE meat products in retail or catering establishments has been associated with (i) cooking and slicing of the products outside of the premises, (ii) preslicing of the products, (iii) slicing by machine rather than by knife, (iv) infrequent cleaning of slicing equipment, (v) using common utensils for serving various products, (vi) lack of physical separation between RTE and raw meat products, (vii) handling of RTE products by the same personnel that handle raw products without changing protective clothing, (viii) packaging in vacuum wrap rather than in cling film or open trays, and (ix) using reusable rather than disposable towels *(74, 96).*

CONTROL OF *L. MONOCYTOGENES* IN RETAIL AND FOOD SERVICE ENVIRONMENTS

According to the ILSI RSI Expert Panel *(123),* avoiding contamination of foods with *L. monocytogenes,* preventing growth of the organism to high levels, and providing science-based but practical education messages targeted to susceptible populations should result in continued reduction of the incidence of listeriosis. In a farm-to-fork food safety approach, retail and food service operations can contribute to meeting the first two of the three objectives outlined above. Efforts to prevent contamination of RTE foods in retail and food service establishments should be based on a series of good manufacturing practices (GMP) and good hygiene practices (GHP) addressing food safety concerns associated with all potential sources of the pathogen in these environments. However, in retail and food service operations validated control measures designed to reduce or eliminate *L. monocytogenes* in RTE foods or to prevent (other than freezing) or slow down (other than refrigeration) its growth are limited.

Retail and food service operators can have access to and use various inexpensive resources for addressing food safety concerns in their establishments. Guidance provided by universities, cooperative extension services, local health departments, and federal agencies may assist retail and food service operations in developing and successfully implementing food safety programs such as GMP, GHP, and HACCP *(11, 199, 203, 210, 254, 257).* The U.S. Food Code, developed by the FDA, is a reference document for local, state, and federal jurisdictions responsible for food safety in retail food stores and food service establishments. It provides guidance for assuring food safety by establishing standards pertinent to management, personnel, food, equipment, utensils, and physical facilities *(257).* Although voluntary, the adoption of the Food Code by all jurisdictions is strongly encouraged by regulatory and public health agencies, because the Code is designed to promote the establishment of uniform national food safety standards. Educational materials developed by universities provide information relative to the incidence and transmission of *L. monocytogenes* in retail environments and guidelines for the successful application, verification, and maintenance of food safety programs and control measures *(199, 203, 210).* Hence, such materials may constitute an important aid for retail operations in developing and implementing appropriate sanitation practices and good retail practices (GRP) pertinent to personal hygiene, food handling, and food storage. Recommendations on GRP also may be provided by relevant trade associations *(86, 87).* Under all circumstances, successful implementation of food safety programs and control measures at the retail and food service level should be based on effective risk communication, education, and training of food managers and handlers *(31, 187).*

Prevention of contamination. Potential sources of microbial contamination of foods in retail and food service establishments include food ingredients or products, the environment, and food handlers *(251).* Given the complexity of retail and food service operations, determination of the original source of a pathogen (food, environment, or food handlers) could be difficult *(176).* Food sources of *L. monocytogenes* in these environments can be either raw food materials or RTE products (including the exterior of their packages) that have been contaminated at food-processing facilities and then are opened and/or handled. Thus, minimizing the likelihood of contamination at the manufacturing level and preventing cross-contamination at the retail and food service level are expected to provide adequate control of the organism *(123).*

Retail and food service operations may reduce the likelihood of contaminated products entering the premises by selecting credible suppliers who are able to assure hazard control on incoming products. Verification of the food safety status of suppliers can be based on supplier audits or purchase specifications *(212).* An understanding of the principles of pathogen control may help retailers and food service operators select suppliers and products *(123).* For prepackaged products contaminated at the manufacturing level and then opened, handled (e.g., sliced), and repackaged at the retail and food service level, inventory control and appropriate product rotation at retail and food service operations may limit pathogen growth and reduce the risk of cross-contamination *(123).* Although the aim of proper inventory rotation is to prevent microbial growth to high levels through minimization of storage time *(123),* when applied at retail or food service inventory control also may contribute to prevention of cross-contamination, which depends on inoculum concentration *(147).* For this purpose, the "first in, first out" concept or novel alternative approaches may be used. Koutsoumanis et al. *(140)* developed an effective chill chain management system that is based on predictive models, intrinsic properties of foods, and time-temperature data and allows for a risk-based prioritization and promotion of product batches to the next stage of distribution. For retail and food service operations that use fresh unprocessed fruits and vegetables to prepare RTE products (e.g., salads, sandwiches), thorough washing with appropriate produce disinfectants and sanitizers may reduce the concentration of *L. monocytogenes* when it is present in incoming products *(23, 113).* Under all circumstances, prevention of cross-contamination of RTE foods with *L. monocytogenes* originating from other foods can be achieved via appropriate GMP specifically designed to meet the operational requirements of the retail and food service establishment. Such practices include segregation of RTE foods and raw ingredients during storage and display, handling by designated personnel using designated utensils, and cleaning and sanitation of utensils and equipment (e.g., knives, slicers, and cutting boards) according to proper sanitation standard operating procedures (SSOP) *(9, 123).*

Regarding environmental *L. monocytogenes* contamination of RTE foods, SSOP appropriate for food-processing and retail and food service operations may provide adequate control of the organism. Proper cleaning and sanitizing of equipment, utensils, and other food contact surfaces should be performed on a routine basis to prevent survival of the pathogen, and storage of utensils under dry and sanitary conditions also is advisable *(123). L. monocytogenes* is able to adhere to a wide range of materials commonly used in food operations *(20)* and can establish persistent contamination niches on food-processing equipment *(158, 159).* Tompkin *(248)* highlighted the high risk of listeriosis associated with the persistence of virulent *L. monocytogenes* strains in food-processing environments through the establishment of niches where normal cleaning and sanitizing procedures are not effective. Niches or harborage sites also may be established in retail and food service environments and serve as potential reservoirs of the organism. Although limited information is available with respect to *L. monocytogenes* harborage sites in retail establishments, they are likely to be similar to those in processing facilities, including both food contact surfaces (e.g., slicers, knives, cutting boards, preparation tables, and refrigerated storage units) and non–food contact surfaces (e.g., drains, grease traps, floors, walls, and air vents) *(203).* Thus, as for environmental sampling programs in food-processing establishments, such programs should be used in retail and food service operations to detect areas of persistent *L. monocytogenes* contamination that may cross-contaminate RTE foods *(123, 248, 249).* Use of materials that are less favorable for bacterial adherence and application of sanitizers capable of lowering the adhesion strength of *L. monocytogenes* also may be required to reduce the risk associated with persistence of this pathogen on food contact surfaces *(178).* A good sanitation program is an efficient and consistent means of preventing contamination of RTE foods with *L. monocytogenes,* and this fact should motivate retail and food service managers toward consistent implementation and monitoring *(213).* The development of effective and practical antimicrobial interventions would be of great value for pathogen control in retail and food service environments. For instance, application (e.g., dipping and spraying) of hot water or food-grade antimicrobial solutions on equipment and utensils (e.g., slicers and knives) at specified time intervals during operation times when thorough cleaning and sanitation cannot be performed may interrupt pathogen transmission during handling and prevent cross-contamination of RTE foods.

Prevention of contamination of RTE foods from food handlers can be achieved through GHP, including exclusion of ill food workers from the workplace, appropriate hand washing, and use of barriers such as gloves, deli wraps, and utensils instead of bare-hand contact with foods *(176, 251).* Poor personal hygiene has been identified as one of the most common human errors leading to illness outbreaks in the United States *(252).* An effective hand washing technique is defined *(251)* by its duration, hand washing agents (e.g., detergents, soaps, sanitizers), water temperature, hand drying method, and frequency. Appropriate hand washing facilities should be available and detailed standard operating procedures (SOP) should be posted in retail and food service environments. A survey of retail food establishments in Minnesota revealed that only 55% of the establishments had fully equipped hand washing stations as outlined in the Food Code; the most common problems were lack of a fingernail brush and inaccessibility of the hand sink *(5).* Both adequate hand washing and use of gloves is recommended for workers who handle RTE foods, and when feasible the direct contact of hands or gloves with food should be avoided by using sanitized serving utensils *(202).* In addition to serving as a source of pathogens, food handlers also may serve as vectors for pathogen transmission in retail and food service environments. An adequate environmental sanitation program and appropriate personal hygiene practices, such as those discussed above, should interrupt this route of transmission *(202).*

The development and implementation of measures to prevent contamination of foods are more challenging at retail and food service operations than in food-processing operations, primarily because the former are open to the public. Unlike manufacturing environments, access to retail and food service environments is not limited to employees; therefore, additional sources of contamination may exist, and certain control approaches (e.g., positive air pressure and footbaths) are not applicable *(123, 203).* This problem is of particular concern in self-serve RTE food operations (e.g., salad bars and buffets), where foods are exposed to a large number of customers and may become contaminated by customer hands or serving utensils *(68).* Such operations should ensure sanitary conditions by meeting the sanitation and GRP requirements described above, providing suitable protection of foods and serving utensils via properly designed sneeze guards or covers (i.e., lids, shields, or doors), and using equipment and utensils that allow for convenient serving by customers and easy cleaning and inspection by staff members *(68).*

Prevention of growth. Strategies for prevention of *L. monocytogenes* growth in retail and food service RTE foods that are part of the ‘‘receive-store-prepare-hold-serve’’ food preparation process *(254)* are limited. Inhibition of growth of the pathogen in food products that are cooked at the processing level and do not undergo any further heat treatment at the retail and food service level before consumption (e.g., deli meats and cheeses) can be accomplished only by appropriate control of storage temperatures and times and by antimicrobial agents applied during processing. The same situation applies to products that do not receive heat treatment at any point of the food chain, such as unprocessed or minimally processed produce.

Various interventions have been developed and are very promising for controlling *L. monocytogenes* in foods, including postpackage decontamination technologies (e.g., thermal pasteurization, irradiation, and high-pressure processing), biopreservation approaches (e.g., lactic acid bacteria, lytic bacteriophages, and bacteriocins), and application of plant extracts with antibacterial activity and chemical antimicrobial compounds *(142, 275)*. The distinct attributes of retail and food service operations compared with processing facilities render application of the above interventions in the former environments problematic, and their implementation usually is limited to the manufacturing level. However, antilisterial ingredients applied at the production level also may inhibit growth of the pathogen during handling, after contamination, and under storage conditions encountered subsequently in the food chain, i.e., on retail and food service premises or in the home *(35, 144, 145)*. The novel concept of antimicrobial packaging, which has been effective against *L. monocytogenes (75, 168),* may be regarded as an intervention for consideration at the retail level. Packaging materials made active against the organism via the incorporation of antilisterial substances could be used at retail operations for repackaging of foods that, because of on-premises handling, are subject to surface contamination (e.g., delicatessen meats or cheeses). Nevertheless, the feasibility, applicability, and antilisterial efficacy of such an intervention must be assessed under the operational conditions existing on retail premises. For instance, the intensive contact between the food product and the packaging material that is required for the antimicrobial packaging technology to be effective may not be assured in foods handled and packaged at retail because such foods are not generally vacuum or skin packaged *(261)*. Antimicrobial packaging would not be effective for sliced products, because the contaminating organism in such products may be located between slices and not in areas that could come in contact with the packaging material.

Temperature control may play an important role in the incidence, concentration, and transmission of *L. monocytogenes* in retail and food service environments. If *L. monocytogenes* contamination occurs, abusive storage or display temperatures of foods may lead to high contamination levels and consequently allow transfer of higher levels of the organism during food handling to food contact surfaces, utensils, and other foods. Loss of temperature control encountered at the retail level can be due to mishandling of food products after distribution from the supplier, delivery of warm product coupled with subsequent ineffective cooling, or operation of retail refrigerators at high temperatures *(95)*. Consumers may also play a role in temperature abuse of chilled retail products during shopping, postpurchase transit to home refrigeration, and/or subsequent inappropriate home storage *(12, 136)*.

Investigation of the temperature distribution of retail store refrigerators in Greece revealed that 32% of refrigerators had temperatures equal to or higher than 9°C and 13.6% were operating at temperatures higher than 10°C *(239)*. Storage temperatures of fish products in retail markets in Finland ranged from 0 to 13.5°C, as reported by Lyhs et al. *(160),* and Nichols et al. *(193)* reported that 15.6% of retail pâté samples (for which storage temperature was recorded) in England and Wales were sold at temperatures exceeding 8°C. According to a nationwide food temperature evaluation study conducted in the United States in 1999, prepackaged lunch meat, deli counter meat, and prepackaged deli products (i.e., potato salad or the equivalent) at temperatures exceeding 5°C were found in 60, 71, and 54% of retail refrigerators, respectively *(12)*.

Storage of RTE sliced meats and pâté on retail or catering premises in the United Kingdom at temperatures higher than 8°C was associated with poor microbiological quality of these products *(74, 96)*. Lewis et al. *(143)* reported that catering premises in the United Kingdom were more likely than retail and production premises to store butter at temperatures higher than 8°C. According to the same investigators, *Listeria* spp., including *L. monocytogenes,* were recovered more often from samples stored or displayed (at production, retail, and catering premises) at temperatures exceeding 4°C than from samples stored or displayed at ≤4°C. Temperature control is particularly important for psychrotrophic pathogens such as *L. monocytogenes (256)*; even slightly abusive storage temperatures may result in prolific growth of the pathogen in certain products *(33, 169, 266)*. Lack of a clear association of storage temperature with incidence or contamination levels of *L. monocytogenes,* as reported in some cases, has been attributed to factors such as small numbers of positive samples, poor reflection of actual display temperatures of RTE foods by the recorded storage temperatures, and greater contribution of cross-contamination than of storage temperature to the transmission of the pathogen *(193, 239)*.

Temperature control appears to be even more important for minimally processed RTE foods such as produce. *L. monocytogenes* is capable of growing in fresh fruits and vegetables under refrigerated storage conditions *(22),* and strict temperature control throughout the food production chain is necessary for improving the safety of such products. According to Odomeru et al. *(198),* temperature abuse of ready-to-use vegetables was associated with increased incidence and levels of *L. monocytogenes.* However, in a study monitoring microbial populations and temperature of fresh broccoli throughout production and distribution, good temperature control from harvest to retail display coincided with failure of recovery of the pathogen from any of the samples and with relatively low counts of total aerobic bacteria, fecal coliforms, and *E. coli (54)*. Increased attention should be focused on foods such as salad bar vegetables because such products may be exposed to multiple sources of contamination *(68)*. Albrecht et al. *(3)* reported that the temperature of salad bar items (i.e., lettuce, tomatoes, broccoli, and cauliflower) obtained from deli operations of supermarkets or grocery stores in the United States ranged from 5.1 to 18.9°C; such temperature conditions in conjunction with the pHs of these items (excluding tomatoes) can support microbial growth if pathogens exist or are introduced during preparation by food workers or handling by customers.

Food operations must ensure that cold storage of RTE products that support growth of *L. monocytogenes* does not exceed a maximum temperature of 4 to 5°C *(68, 257)*. Placement of such products close to lights during display in retail and food service cabinets and irregular defrost cycles in refrigeration equipment may result in product temperatures higher than 10°C *(242)*. Thus, maintenance of temperatures close to the freezing point (−2 to −1°C) in retail distribution of refrigerated foods and in food service operations may be advisable *(242)*. Because refrigerators in self-serve operations may be subject to frequent opening and salad bar foods can be easily exposed to ambient temperatures, the cooling capacities of such systems must be evaluated frequently and corrected accordingly *(68)*.

Concise and informative label dating of products from manufacturers and in-store label dating of products that are handled and/or prepared within retail and food service establishments can be useful for determining appropriate storage times and consumption deadlines, both in retail operations and at home *(123)*. Label dating of RTE products, applied either at the processing or at the retail level, should be safety rather than quality oriented, if *L. monocytogenes* growth to hazardous levels is to be prevented *(190)*. According to the NACMCF, labeling of the format "use within *x* days" of opening or purchase may be effective for controlling the pathogen when coupled with good temperature control *(190)*. Based on the date marking requirements of the 2005 Food Code, which were developed to allow no more than 1-log growth of *L. monocytogenes,* storage of potentially hazardous RTE foods in food establishments should not exceed 7 days at 5°C or 4 days at 7°C *(257)*. These requirements apply to on-premises prepared foods and to packages of commercially processed foods that have been opened, provided that in both cases these foods are held in a food establishment for more than 24 h and the day of food preparation or opening of the original package is counted as day 1 *(257)*. Lianou et al. *(144, 145)* evaluated the fate of *L. monocytogenes* in delicatessen products (i.e., cured ham and uncured turkey breast), which were commercially available with and without a mixture of potassium lactate and sodium diacetate, during aerobic storage at 7°C under two contamination scenarios: (i) at processing and (ii) at retail or in the home. The findings of these studies indicated that although processing plant contamination of products without antimicrobials was in general the worst case scenario, length of aerobic storage also was an important parameter with respect to *L. monocytogenes* concentrations. Storage for 12 days of products without antimicrobials resulted in similarly high pathogen populations regardless of the contamination scenario. In the retail and home contamination scenario of uncured turkey breast without lactate and diacetate, *L. monocytogenes* increases within 3 days of aerobic storage (7°C) exceeded 1 log CFU/cm^2 *(145)*. Such observations demonstrate that the Food Code requirements outlined above may need to be reassessed regarding refrigerated retail storage of uncured poultry products when no antimicrobial ingredients are incorporated in their formulation *(145)*. Hence, storage times of RTE products at every segment of the food chain must be determined based on the handling and storage conditions expected to be encountered, the type of product and its potential for supporting growth of *L. monocytogenes,* and the application and anticipated effectiveness of antilisterial interventions.

HACCP systems. The HACCP principles, which are being more frequently implemented for the control of foodborne pathogens in food manufacturing environments, also can be useful in retail and food service settings. Implementation of HACCP concepts in certain food-processing establishments is mandatory by regulations developed by the FDA and the USDA. However, such regulations are not in place for retail and food service operations where although the HACCP philosophy is embraced in the Food Code its implementation is voluntary *(257)*. According to Mortlock et al. *(187)* in a survey conducted in the United Kingdom in 1997, manufacturers were five times more likely than retailers and four times more likely than caterers to be using HACCP systems, an observation that was also supported by the fact that HACCP training was received by 54% of food managers in the manufacturing sector and by only 10% of managers in the retail sector and 20% of managers in the catering sector. In the same survey, factors that appeared to be associated with the use of HACCP systems included business status and size, level of food hygiene, risk perception, and attitudes towards food safety among business managers.

The inherent characteristics of retail and food service operations render implementation of HACCP systems more challenging than in food-processing operations. In addition to commitment by top management, which is vital for successful HACCP implementation in both environments, HACCP systems intended to be used at retail and food service establishments must be simple, easy to use, and flexible *(174, 187, 212)*. HACCP methodology and terminology must be as consistent as possible throughout the food industry, and it has been suggested that HACCP systems should be tailored to the needs of retail and food service operations through modifications in the practical application or interpretation of the system, while keeping its principles and definitions the same *(174)*. Methods of using the HACCP principles in developing HACCP-based systems that can be functional in retail operations as part of a total quality management approach were discussed by Reimers *(212)*.

In retail and food service operations, where many different types of foods may be handled or prepared simultaneously, a unit operations process approach can be more efficient when conducting a hazard analysis. According to this approach, food flows are divided into broad categories (food preparation processes), and hazard identification and application of control measures are ascribed to each of the categories *(254)*. Critical control points should be as few as possible and able to be monitored on an ongoing basis, and established critical limits should be achievable within the retail and food service environment *(30, 212)*. Monitoring of critical control points should be conducted by in-house personnel and actively supervised, and additional verification may be performed by health department staff or other regulatory personnel *(30)*. Corrective actions and record-keeping also can be challenging in a constantly changing retail and food service operation. The use of decision charts and flow diagrams at identified critical control points can be beneficial in assuring that corrective actions are initiated when required *(212)*. Process- rather than product-specific record-keeping systems and utilization of efficient management information systems (e.g., electronic) instead of paper systems also may simplify the system *(212, 254)*.

Regardless of whether formal HACCP or HACCP-based systems are embraced by retail and food service operations, certain factors are considered of major importance for effective implementation of these systems in these sectors of the industry. Such factors include clarification of the role of regulatory personnel and of the criteria for compliance (internal HACCP plan of the establishment or regulations of local jurisdictions) and open and ongoing communication between the retail and food service industry and regulatory authorities *(149, 174)*. The value of the utilization of HACCP principles by regulatory jurisdictions in conducting risk-based inspections in retail and food service operations has been acknowledged. A manual developed by the FDA proposes strategies for applying HACCP principles to risk-based inspections, thus assisting regulatory food safety professionals in evaluating and improving food safety management systems implemented by retail and food service establishments *(255)*. Adoption of the strategies outlined in this manual also may strengthen the relationship and promote partnerships between regulators and retail and food service operators, facilitating in this manner the active role of regulators in improving food safety in retail and food service establishments *(255)*.

Education and training. Education and training programs targeting food managers and food workers are necessary for the control of *L. monocytogenes* in retail and food service establishments. Limited or inadequate food safety knowledge (i.e., knowledge of foodborne diseases, food hygiene, and safe food handling practices) among food handlers has been demonstrated in several instances *(8, 85, 164)*. Mortlock et al. *(188)* reported that retail businesses in the United Kingdom were more likely to employ food handlers with no food hygiene qualifications than were other sectors of the food industry (i.e., manufacturing and catering operations). Analysis of restaurant inspection data collected between 1996 and 2000 in Oklahoma revealed a high number of recurrent violations of selected Food Code items, an indication that inspections cannot by themselves ensure improvements in establishments not complying with food safety standards *(206)*. Inspections are usually of short duration, providing only sporadic evaluation of parts of operations, and judgments and evaluations may vary with inspection practices *(30, 206)*. The Food Code states that the person in charge in each establishment shall ensure that employees receive proper food safety training according to their duties, and managers should demonstrate food safety knowledge by passing a test that is part of an accredited program *(257)*.

Angelillo et al. *(8)* reported that continuing education courses offered to food handlers in Italy were associated with positive attitudes toward foodborne disease control. A survey undertaken in retail food establishments in Minnesota revealed that hand washing compliance by food workers was positively associated with hand washing knowledge of the designated person in charge and with development and implementation of appropriate training methods *(5)*. Similarly, food safety training significantly improved the knowledge and behaviors of food workers in emergency food relief organizations in western New York *(85)*. Food hygiene training along with HACCP-specific training of both food managers and employees are necessary for successful implementation of HACCP systems *(165, 174, 225, 264)*. According to Mortlock et al. *(187)*, among production, retail, and catering businesses using HACCP systems, specific training on the system was significantly associated with adoption of all seven HACCP principles. However, HACCP education and training must be performed on a continuous basis to be able to keep up with high employee turnover commonly encountered in retail and food service operations *(174)*. Iterative training also may be required for a long-term positive effect to be achieved *(260)*.

Education and training approaches such as videos, computer-based training, food safety icons, self-audit checklists, and verification of specific learning tasks can be useful in retail and food service operations *(123)*. Nevertheless, food safety training and reported knowledge are not always associated with changes in behavior and safe food handling practices *(8, 48, 71, 164)*. Additional factors that may be linked to food handling behavior include age, risk perception, work responsibilities, and type of establishment *(48, 104)*.

CONCLUSIONS

The information provided above indicates that the role of retail and food service environments in contamination of RTE products with *L. monocytogenes* should not be overlooked. The presence of the pathogen in various RTE products, both prepackaged and in-store packaged and occasionally at high concentrations, in conjunction with the multiple transmission routes that may be encountered in retail and food service premises render control of the organism as critical in these establishments as in food-processing operations. Despite the unique challenges that retail and food service operations must face, a comprehensive food safety system based on the philosophy of HACCP and a series of sound prerequisite programs (i.e., GMP, GHP, SOP, and SSOP) can provide effective control of *L. mono-*

cytogenes in these environments. However, competent delivery of food safety education and training to retail and food service managers and food handlers must occur for successful implementation of such a system.

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