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Food Safety Knowledge of Consumers and the Microbiological and Temperature Status of Their Refrigerators

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ABSTRACT

The objectives of this study were to examine domestic food safety knowledge levels of consumers, establish the levels and incidence of bacterial contamination and operational temperatures in domestic refrigerators, and identify areas in which consumer food safety education is necessary in Ireland. A food safety knowledge questionnaire applied to a representative sample of households ($n = 1{,}020$) throughout the island of Ireland found the gaps in consumer food safety knowledge. Analysis of swab samples ($n = 900$) recovered from the domestic refrigerators in these households showed average total viable counts of 7.1 log CFU/cm^2 and average total coliform counts of 4.0 log CFU/cm^2. Analysis of swab samples also detected the incidence of *Staphylococcus aureus* (41%), *Escherichia coli* (6%), *Salmonella enterica* (7%), *Listeria monocytogenes* (6%), and *Yersinia enterocolitica* (2%). *Campylobacter jejuni* and *E. coli* O157:H7 were not detected in domestic refrigerators. The temperature profiles of a subset of the sampled refrigerators (100) were monitored for 72 h, and 59% were found to operate, on average, at temperatures above the recommended 5°C. Knowledge and temperature survey results varied considerably, but consumers who scored better in terms of basic food safety knowledge had reduced levels of bacterial contamination in their refrigerators and reported a reduced incidence of food-associated illnesses. This study confirms the effect of basic food hygiene knowledge on hygienic practice and identifies specific areas for emphasis in the development and delivery of effective food safety risk communication messages to consumers.

Foodborne illness is a threat to the health and well-being of consumers, involving major economic losses to individuals in terms of lost working days and substantial clinical and other costs to the health and welfare sectors. Although many consumers tend to associate foodborne illness with eating outside the home, research suggests that many food poisoning cases are associated with domestic food preparation *(19).* Many of these cases are associated with the most common faults in domestic food hygiene practice, such as inappropriate storage, inadequate cooking, and cross-contamination *(16).* The importance of domestic food preparation practices in foodborne illness is supported by epidemiological data. Outbreak investigations in Scotland suggest that most food poisoning occurs in private houses and is associated with mishandling of food *(3).* A sentinel study in The Netherlands by Hoogenboom-Verdegaal and Postema *(21)* indicated that 80% of *Salmonella* and *Campylobacter* infections were associated with domestic food preparation. Similarly, the domestic kitchen has been implicated as a major source in the high incidence of family-associated foodborne disease in Germany *(26)* and France *(20).*

Currently, much of the government and regulatory authority effort to reduce the dangers posed by foodborne pathogens has focused on the application of more effective food safety management systems, such as hazard analysis and critical control point (HACCP) within the food production, processing, and retail elements of the food chain. Such efforts are certainly worthwhile, but it is also clear that poor knowledge and practice among domestic food handlers can often negate much of the effort made in improving and maintaining food safety at earlier stages of the food chain *(5, 23).*

Progress in resolving or reducing the risks involved in failures in consumer food safety practice is dependent on correctly identifying the hygiene errors that consumers make in their own kitchens and on developing education or information strategies that get the corrective messages and practices to consumers, or to relevant subgroups of consumers *(6).* In line with the above emphasis on food production, processing, and retail, relatively few investigations have examined consumer food safety knowledge and practices. The objective of this study was to identify gaps in food safety knowledge among consumers and the hygiene errors that most frequently occur in domestic kitchens so that education programs can be tailored to address these issues.

MATERIALS AND METHODS

Knowledge survey. A food safety questionnaire was designed involving 33 questions covering food safety issues (such as refrigerated storage of food, cross-contamination, defrosting and reheating, cooking, domestic food poisoning, food hygiene education, and microbial knowledge) and 5 questions covering sociodemographic issues. A pilot study of the questionnaire took place in 10 houses in a suburb of Dublin, Ireland. No revisions were made to the questionnaire following this pilot as no problems

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were evident in either administration, timing, or consumer understanding of the questionnaire. Administration of the interviews took the form of face-to-face interviews in the respondents' homes, immediately after their agreement to take part in the study. The questionnaire took approximately 10 min to complete. All responses to the questionnaire were unprompted.

Representative sampling areas ($n = 102$) were identified across the island of Ireland by the Marketing Research Bureau of Ireland (MRBI), in line with the overall population patterns on the island of Ireland. Quota controls were established in terms of the number of people in respondent households, occupations of the chief wage earners, and socioeconomic status of the main wage earner. In terms of the socioeconomic status of the chief wage earner, each person was classified into one of seven social grades on the basis of their occupation. Social class A includes upper middle-class occupations such as senior professionals, chartered accountants, architects who are partners in the business, dentists, and senior executives. Social class B includes middle-class occupations ranging from recently qualified professionals and army lieutenants to head masters in small schools. Class C1 are other white-collar workers, including junior civil servants and secretaries. Class C2 are skilled workers, such as electricians. Class D are unskilled workers. Class E includes casual workers and pensioners dependant on state pensions with no other income and those on social security. Class F are farmers.

Households were selected at random. The random route procedure involved going to the starting address, completing the first interview there, then calling at every fifth house on the left-hand side of the road. On reaching the end of that road, a left turn was taken and every fifth house was called at; on reaching the end of that road, a right turn was taken and every fifth house was called at. Ten or more households in each location were visited by this random route procedure until the quota and target number (10) had been achieved in each area. No notification was given before the visit. The questionnaires were administered during daylight hours.

In total, information was recovered from 1,020 households. All the respondents were ''mainly'' responsible for food preparation and cooking in their household. After completion of the questionnaire, permission was sought to take swab samples for subsequent microbiological analysis. Permission was also sought from 100 householders to measure their refrigerator temperature for a 72-h period.

Microbiological survey. Cellulose sponge swabs (10 by 10 by 1 cm, Sydney Heath and Son, Stoke-on-Trent, Staffordshire, UK), previously tested to ensure they did not contain inhibitory substances for bacteria, were prepared in sterile bags, moistened with 5 ml of maximum recovery diluent (Oxoid, Unipath Ltd., Basingstoke, UK) and sterilized by autoclaving. Each swab was used to sample the inner sides and floor ($\sim$2,076 cm^2) of the refrigerator by the inverted bag technique *(27)*, transported to the laboratory in a cool box at approximately 4°C, as described by Cagney et al. *(10)*, and microbiologically examined within 48 h.

Swabs were aseptically transferred into a sterile stomacher bag (Stomacher 400, Seward Medical, London, UK) and homogenized for 2 min with 250 ml of buffered peptone water (BPW CM509, Oxoid) with a Colworth Stomacher (model BA 6021, A.J. Seward and Company Ltd., London, UK). Serial dilutions of the resultant bacterial suspensions (in maximum recovery diluent) were plated onto plate count agar (tryptone glucose yeast agar, Oxoid) to obtain total viable counts (TVCs). These plates were incubated at 30 $\pm$ 1°C for 48 $\pm$ 3 h *(17)* or onto Chromocult coliform agar (Chromocult, Merck, Darmstadt, Germany) to obtain total coliform counts (TCCs). These plates were incubated at 37 $\pm$ 1°C for 24 $\pm$ 1 h *(14)*.

Presumptive *Escherichia coli* (dark blue/violet colonies on the Chromocult coliform agar) was confirmed by plating onto Levine's eosin methylene blue agar (Oxoid) and phenol red sorbitol agar, and completion of the range of biochemical tests described by Finney et al. *(14)*. Colonies displaying a green metallic sheen on Levine's eosin methylene blue agar and no fluorescence on UV-illuminated phenol red sorbitol agar with 4-methylumbelliferyl-B-D-glucuronide (Oxoid) were analyzed further as described by Cagney et al. *(10)*.

Salmonella spp. were isolated and confirmed as described by Pearce *(31)*. *Campylobacter* spp. were isolated and confirmed as described by Cloak et al. *(11)*. *Yersinia enterocolitica* was isolated and confirmed as described by Logue et al. *(28)*. *Listeria monocytogenes* was isolated and confirmed as described by McClain and Lee *(29)*. *Staphylococcus aureus* was isolated by plating onto Baird Parker medium (Baird Parker agar base with egg yolk tellurite emulsion, Oxoid). The plates were incubated at 37°C for 48 h. From each plate, five typical colonies of *S. aureus* were tested by Gram stain and tested for the production of coagulase, catalase, and DNase; the fermentation of mannitol, and oxidation. Primary identification involved subculturing of typical *S. aureus* colonies onto DNase plates (Oxoid) and blood agar plates (Columbia base agar and 5% lysed horse blood, Oxoid) and incubating at 37°C for 24 h. Colonies positive for all the aforementioned tests were maintained on tryptic soy agar (TSA; Oxoid) and confirmed by testing of the clumping factor (Staphylase Test Kit, DR595, Oxoid).

Temperature survey. Testo 175 temperature data loggers (Testo Ltd., Alton, Hampshire, UK), adjusted to record the internal refrigerator temperature every 10 min over a 72-h period, were placed on the middle shelves of 100 of the domestic refrigerators swabbed during the study.

Data analysis. The questionnaire responses and microbiological results were analyzed with SPSS (version 10.1) software. Pearson's chi-square tests were performed to examine the relationships between responses and microbial status of the refrigerator.

RESULTS

Demographics. The demographic details of the survey respondents are given in Table 1.

Food handling, refrigeration, and storage. The survey questions and results are summarized in Table 2. The first question asked was, ''Thinking about the last time you went shopping for raw meat, how much time lapsed between placing it in your shopping basket and storing it in your fridge or freezer?'' Respondents reported the time lapse from retail to domestic refrigerator as less than 30 min (58%), 30 to 90 min (35%), 90 min to 3 h (6%), or more than 3 h (1%). The next question was, ''At what temperature do you think that your refrigerator should be?'' Only one-fifth of respondents (22.4%) were aware of the correct refrigeration temperature of 0 to 5°C. Respondents were asked whether they had a thermometer in their refrigerator. Just less than a quarter (23.2%) of surveyed refrigerators reportedly contained a thermometer. Respondents in lower income households (C2DE) were significantly ($P >$ 0.001) less likely to know the correct refrigeration temper-

TABLE 1. *Demographic details of the food safety knowledge respondents*

	Demographic of respondents	Response (%)
Location	Urban	75
	Rural	25
Gender	Male	23
	Female	77
No. of people in household	1–3	63
	4–5	28
	5+	9
Socioeconomic group	ABC1	39
	C2DE	51
	F1:F2	9
	Refused to answer	1
Employment status	Full time	24
	Part time	20
	Unemployed	6
	Student	4
	Retired	19
	Full-time housewife	26
	Refused to answer	1
Age	>18	1
	19–24	10
	25–34	20
	35–44	19
	45–54	17
	55–64	15
	65+	19

ature. Younger respondents (<25 years old) were significantly ($P < 0.005$) more likely to know the correct refrigeration temperature than older respondents (>25 years old). With regard to storage of raw meat in the refrigerator, approximately half of consumers reported storing raw meat correctly (on the bottom shelf or in the bottom drawer) in their refrigerators.

Respondents were asked, ''How do you clean your refrigerator?'' Respondents indicated a variety of agents used for cleaning their refrigerator, including washing-up liquid (39.4%), sanitizer or detergent (31.7%), baking soda (16.3%), vinegar (10.4%), salt (0.1%), and water (2.1%). They used these cleaning agents hot (10.8%), warm (71.3%), or cold (7%), applied with a dishcloth (54.7%), a clean cloth (21.1%), a paper towel (12%), a disposable dish cloth (9.4%), or a sponge (2.8%).

Cross-contamination. Responses in relation to practices to prevent cross-contamination on knives included washing the knife with detergent and hot water (72.8%), wiping the knife with a cloth (13.3%), rinsing the knife with cold water (7.5%), using the knife as-is (i.e., without cleaning, 2.8%), using separate knives for raw meat and cooked foods (2.2%), and washing the knife with detergent, hot water, and bleach (1.3%). Responses in relation to practices to prevent cross-contamination on cutting boards included washing the board with detergent and hot water (72%), wiping the board with a cloth (13.1%), rinsing the board with cold water (6.1%), reusing the board without cleaning (3.5%), using a separate cutting board (3%), and washing the board with detergent, hot water, and bleach (3%).

Of 56.5% of the respondents who had a pet, 302 (52.4%) allowed the pet into the kitchen.

Respondents were asked, ''On what occasions do you think it is important to wash your hands?'' The occasions mentioned were before meals (69.9%), after handling raw meat (64.6%), and after using the toilet (49.6%). Only 7% reported that hand washing was important after touching a pet. Respondents described a variety of hand washing (see Table 2). The methods mentioned included ordinary soap and warm or hot water (63.7%), antibacterial soap and warm or hot water (21.7%), washing-up liquid and hot water (4.1%), rinsing with warm or hot water (without soap, 6.6%), rinsing with cold water (3.0%), and wiping with a tea towel, dish cloth, or disposable cloth (J-cloth, 0.9%).

Defrosting, storing, and reheating. Respondents reported defrosting frozen meat at room temperature (56.2%), in the refrigerator (23.4%), or in a microwave oven (13.1%). Respondents stored meat leftovers in the refrigerator (57.6%), in the oven (6.0%), at room temperature on a table or counter (5.2%), in the freezer (2.9%), and in an unrefrigerated cupboard (1%). Almost one third (27.8%) of respondents cited that this question regarding storage of leftovers was not applicable to them. In terms of reheating meat, respondents reported heating leftovers until they were hot (42%), warm (10.1%), or cold (20.1%), and this question was not applicable to 27.8% of respondents.

Cooking. When respondents were asked how they cook roast beef, steak, and beef burgers, they reported that meats were cooked until well done (roast beef, 83.7%; steak, 75.6%; beef burgers, 82.7%), medium (roast beef, 9.7%; steak, 15.8%; beef burgers, 2.5%), or rare (roast beef, 3.2%; steak, 5.3%; beef burgers, 0.1%). No respondents reported eating raw roast beef or beef burgers, but 0.3% reported eating raw steak. Some respondents reported that the question was not applicable (roast beef, 3.3%; steak, 3%; beef burgers, 14.7%).

Respondents used a variety of tests to check that red meat was sufficiently cooked, including visible inspection (39.7%), until the juices ran clear (28%), when brown inside (12.5%), when cooked for a specified period (7.5%), or until the meat fell from the bone (5%). For poultry, respondents checked that such meat was sufficiently cooked by visible inspection (32.5%), until the juices ran clear (30.6%), until brown outside (13.6%), after cooking for a specified period (8.4%), until meat fell from the bone (8.5%), or by taste (2.8%).

Domestic food poisoning. When asked to estimate the percentage of food poisoning associated with domestic food preparation, 38.9% of respondents suggested up to 20% of cases, 18.7% of respondents suggested between 21 and 40% of cases, 23.4% of respondents suggested between 41 and 60% of cases, 13.9% of respondents suggested between 61 and 80% of cases, and 1.7% of respondents suggested between 81 and 100% of cases. The remainder, (3.3%) did not express an opinion. Those consumers who believed that

TABLE 2. *A summary of the main survey questions and their respective answers*

Question	Answer
Thinking of the last time you went shopping for raw meat, how much time lapsed before it was stored in the refrigerator or freezer?	<30 min (58%) 30–90 min (35%) 90–180 min (6%) >180 min (1%)
At what temperature do you think your refrigerator should be operating?	<0°C (4%) 1–5°C (22%) 6–10°C (6%) >10°C (1%) Unsure (67%)
Do you have a thermometer in your refrigerator?	Yes (23%) No (77%)
Do you have a thermometer in your freezer?	Yes (12%) No (64%) Not applicable (14%)
When you refrigerate raw meat, where do you store it?	Top shelf (13%) Middle shelf (10%) Bottom shelf or drawer (53%)
What cleaning agent do you use to clean your refrigerator?	Washing-up liquid (39%) Sanitizer (18%) Baking soda (16%) Detergent (13%) Vinegar (10%) Water (2%) Salt (0.1%)
What temperature is the cleaning agent you use to clean your refrigerator?	Hot (11%) Warm (60%) Luke warm (11%) Cold (7%)
What cleaning cloths/other do you use to clean your refrigerator?	Disposable cloth (J-cloth) (9%) Paper towel (12%) Clean cloth (21%) Dish cloth (55%) Sponge (3%)
When you cut raw meat and need to use the knife again, what do you do?	Reuse the knife as it is (3%) Rinse with cold water (8%) Wipe with a cloth (13%) Wash with detergent and hot water (73%) Wash with detergent, hot water, and bleach (1%) Use a different knife (2%)
When you cut raw meat and need to use the cutting board again, what do you do?	Reuse the cutting board as it is (4%) Rinse with cold water (6%) Wipe with a damp cloth (13%) Wash with detergent and hot water (72%) Wash with detergent, hot water, and bleach (3%) Use a different board (3%)
Do you allow a pet into your kitchen?	Yes (30%) No (27%) Not applicable (43%)
On what occasions do you think it is important to wash your hands?	Before preparing meals (70%) After using the toilet (50%) After handling raw meat (65%) After feeding or touching pets or other animals (7%) After gardening (1%) When I come home from work (1%) After changing a baby's nappy (2%)
How do you wash your hands?	Ordinary soap and warm or hot water (64%) Antibacterial soap and warm or hot water (22%) Washing-up liquid and hot water (4%) Warm or hot water only (7%) Cold water only (3%) Wipe with a tea towel, dish cloth, or J-cloth (1%)

TABLE 2. *Continued*

Question	Answer
How do you defrost frozen meat?	At room temperature (56%) In the refrigerator (23%) In the microwave (13%) Cook frozen (1%) In boiling water (1%) Not applicable (6%)
Where do you store leftovers?	In the refrigerator (58%) In the freezer (3%) On the countertop or table (5%) In the oven (6%) In a press or cupboard (1%) Other (please specify) (0%) Not applicable (28%)
Considering the last time you ate leftovers, how would you describe their temperature?	Cold (20%) Warm (10%) Hot (42%) Not applicable (28%)
How well cooked do you like roast beef?	Raw (0%) Rare (3%) Medium (10%) Well done (84%) Not applicable (3%)
How well cooked do you like steak?	Raw (0%) Rare (5%) Medium (16%) Well done (76%) Not applicable (3%)
How well cooked do you like beef burgers?	Raw (0%) Rare (0%) Medium (3%) Well done (83%) Not applicable (15%)
How do you check that red meat is sufficiently cooked?	When the juice runs clear (28%) When it tastes cooked (4%) When it looks cooked (visible inspection) (40%) When the meat falls away from the bone (5%) When the meat is brown on the inside (13%) When the meat has the correct thermometer reading (2%) When the meat has been cooked for the stated time (8%) Other (please specify) (0) Not applicable (1%)
How do you check that poultry is sufficiently cooked?	When the juice runs clear (31%) When it tastes cooked (3%) When it looks cooked (visible inspection) (33%) When the meat falls away from the bone (9%) When the meat has a brown outer coating (14%) When the meat has the correct thermometer reading (2%) When the meat has been cooked for the stated time (8%) Other (please specify) (1%) Not applicable (1%)
What percentage of food poisoning do you think is associated with the home?	Up to 20% (39%) 21–40% (19%) 41–60% (23%) 61–80% (14%) 81–100% (2%)
Have you or any member of your family suffered from food poisoning in the last 12 months?	Yes (19%) No (81%)

TABLE 2. *Continued*

Question	Answer
If you or your family experienced food poisoning in the last 12 months, where do you think you got it?	Restaurant (32%) Home (27%) Take-away (20%) Mobile take-away (13%) Barbeque (2%) Crèche (1%)
Where did you learn about food safety?	Parent, guardian, or grandparent (52%) Friend (5%) Cookery class (4%) School (28%) Third-level course (7%) On-the-job training (8%) Magazine or newspaper (17%) Experience (26%) Television (21%) Food safety agency (3%) Internet (1%) Food safety brochure (6%) Medical professional (1%) Radio (2%) Brochure (5.7%) Other (2%)

less than 20% of food poisoning occurred in the home were significantly ($P < 0.05$) less likely to wash their hands correctly.

When questioned about direct experience of food poisoning within the last 12 months, approximately four fifths (80.5%) of respondents claimed the question was not applicable because neither they nor a family member had suffered from food poisoning during that time. Of those who had experience of food poisoning within the last 12 months, respondents suspected restaurants (31.8%), the home (26.7%), take-away (20%), mobile take-away (food van) (12.8%), barbecues (2.0%), and crèches (day care/nursery) (0.5%). Of those who had experience with food poisoning within the last 12 months, 6.2% did not express an opinion as to the potential source of the illness.

Food hygiene education. Respondents reported learning correct food safety practices from their parents or grandparents (52.1%), school (28.4%), general experience (25.6%), television (21%), newspapers or magazines (16.6%), work (8%), third-level education (6.5%), brochures (5.7%), friends (4.9%), cooking classes (4.3%), food safety agencies (2.9%), radio (1.8%), medical doctors (1.1%), and the internet (0.5%).

Microbial knowledge. The levels of awareness of food poisoning agents is summarized in Table 3. Respondents reported having heard of *Salmonella* (92.9%), *E. coli* O157 (77%), and *L. monocytogenes* (45.2%). A range of other pathogens, such as *Campylobacter*, *Bacillus cereus*, *S. aureus*, *Clostridium perfringens*, *Clostridium botulinum*, *Y. enterocolitica*, and viruses, were reported by <20% in each case. Respondents were asked the open-ended question, ''Do you associate any food with . . .'' each pathogen mentioned. In general, respondents had limited success in associating pathogens with particular foods. The most fre-

TABLE 3. *Knowledge of different food poisoning agents and associated foods*

Bacteria	Rate of respondent recognition (%)	Correct association with relevant food (% of those who had heard of the agent)		
Salmonella	92.9	Poultry: 23.1%	Pork: 4.7%	Eggs: 44.0%
L. monocytogenes	45.2	Beef: 9.1%	Soft cheese: 28.1%	Vegetables: 2.9%
Shigella	5.6	Meat: 7.1%	Water: 8.9%	Salads: 1.8%
E. coli O157	77.0	Beef: 38.7%	Raw milk: 2.1%	Burgers: 15.9%
Campylobacter	10.2	Poultry: 19.6%	Pork: 1.0%	Eggs: 3.9%
B. cereus	10.1	Rice: 9.9%	Cream/milk: 5.0%	Soup: 0.0%
S. aureus	2.5	Milk: 2.5%	Eggs: 0.6%	People: 21.7%
C. perfringens	5.2	Meat: 9.6%	Spices: 0.0%	
C. botulinum	16.7	Canned foods: 14.4%	Meat: 12.6%	
Y. enterocolitica	1.5	Pork: 33.3%		
Viruses	18.3	Shellfish: 6.6%		

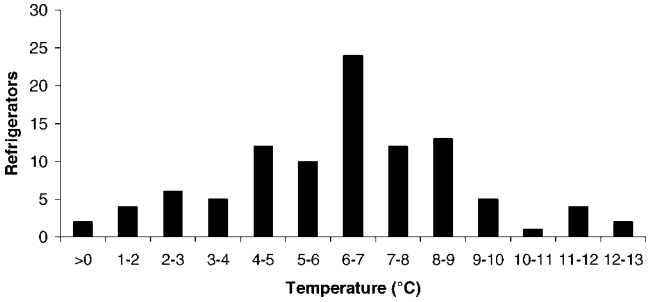

FIGURE 1. *Mean temperature frequency distribution for domestic refrigerators in Ireland.*

quently reported association was between *Salmonella* and eggs (44%). Some of the other associations reported included *E. coli* O157 and beef (38.7%) and *L. monocytogenes* and soft cheese (28.1%). Interestingly, respondents with more correct microbial knowledge were significantly ($P < 0.05$) more likely to correctly store raw meat and to correctly clean knives and cutting boards.

Refrigerator temperatures. In the survey of 100 refrigerators, the observed mean temperatures varied between −1.7 and 11.8°C, and 71 had average temperatures above 5°C. The maximum temperature was 20.7°C, and the minimum temperature was −7.9°C (Fig. 1).

Microbiological survey. TVC varied between not detected and 9.56 log CFU/cm^2. TCC varied between not detected and 6.43 log CFU/cm^2. The average TVC and TCC were 7.1 and 4.0 log CFU/cm^2, respectively (see Table 4). A number of the target pathogens were detected in the sampled refrigerators (i.e., *S. aureus* [41%], *Salmonella* spp. [7%], *E. coli* [6%], *L. monocytogenes* [6%], and *Y. enterocolitica* [2%]). *Campylobacter* spp. and *E. coli* O157:H7 were not detected. Fifty-two percent of refrigerators contained at least one of the aforementioned pathogens.

Statistical analysis of consumer knowledge and microbial survey data suggested the following.

(i) Urban consumers had significantly ($P < 0.05$) higher TVCs and general incidence of pathogens in their refrigerators than rural consumers (Table 5).

(ii) Respondents younger than 25 years of age are more likely to have one or more pathogens present in their refrigerators.

(iii) Respondents from the socioeconomic group ABC1 had a significantly ($P < 0.05$) higher general incidence of pathogens than the C2DE group.

(iv) Respondents from the socioeconomic group ABC1 had significantly ($P < 0.05$) higher TVCs than the C2DE group.

(v) Respondents with a third-level qualification had significantly ($P < 0.05$) higher TVCs in their refrigerators than respondents without a third-level qualification.

(vi) Respondents who reported correct hand washing procedures (89.5%) had significantly ($P < 0.05$) lower TVCs, TCCs, and incidences of pathogens than respondents who washed their hands incorrectly (10.5%).

(vii) Respondents who had heard of *Salmonella*, *Campylobacter*, *E. coli*, or *L. monocytogenes* were more likely to wash their hands correctly ($P < 0.05$).

TABLE 4. *Quantitative and qualitative microbial contamination in Irish domestic refrigerators*

Bacterial count (log CFU/cm^2)	
Mean total viable count (TVC)	7.1
Mean total coliform count (TCC)	4.0
% incidence (mean)	
Campylobacter	0
E. coli O157	0
Y. enterocolitica	2
L. monocytogenes	6
E. coli	6
Salmonella	7
S. aureus	41

(viii) Respondents who reported correct knife and cutting board cleaning procedures were more likely to know the correct refrigeration temperatures ($P < 0.05$) than respondents who reported an incorrect cleaning procedure for these utensils. The respondents who reported this correct cleaning procedure were more likely to cook meat and poultry correctly ($P < 0.05$). These respondents also had significantly ($P < 0.05$) lower TVCs and incidences of pathogens in their refrigerators than the respondents who reported an incorrect procedure for washing the knife and cutting board. Interestingly, respondents who reported that they or a member of their family had suffered food poisoning in the previous 12 months had significantly ($P < 0.05$) higher TVCs and incidences of pathogens in their refrigerators.

TABLE 5. *A summary of the significant associations between demographics, food safety knowledge, and microbiological survey data*

Urban consumers had significantly higher TVCs and general incidence of pathogens in their refrigerators
Respondents younger than 25 years of age were more likely to have pathogens present in their refrigerators
Socioeconomic group ABC1 had a significantly higher TVC and incidence of pathogens in their refrigerators compared with C2DE group
A knowledge of correct hand washing procedures resulted in significantly reduced refrigerator TVC, TCC, and pathogen incidence
Respondents who had a basic awareness of pathogens like *Salmonella*, *Campylobacter*, *E. coli*, or *L. monocytogenes* tended to wash their hands correctly
Respondents who knew the correct knife and cutting board hygienic procedures to prevent cross-contamination were more likely to know the correct refrigeration temperatures and safe meat and poultry cooking practices
Those with a lack of knowledge of how to prevent cross-contamination via knives and cutting boards had significantly higher refrigerator TVC and incidence of pathogens
Respondents who reported that they or a family member had suffered food poisoning in the previous 12 months had significantly higher refrigerator TVC and incidence of pathogens

DISCUSSION

Some potential for temperature abuse exists because 7% of respondents allow more than 90 min to lapse between shopping and chilled or frozen storage. Any practice in which food is held over time in temperatures conductive to bacterial growth is a potential risk in terms of food safety because it allows more rapid growth of spoilage microorganisms and the growth of food pathogens, if they are present *(21).* One method of helping to ensure that perishable food remains microbiologically safe after purchase is to place it in a refrigerator or freezer as soon as possible.

In this study, 22.4% of consumers were aware of the correct refrigerator temperature. This can be compared with results from surveys in the United Kingdom, the United States, and Australia, where 10%, 54%, and 32.3% of consumers knew the correct refrigeration temperature *(4, 23, 32).* More than three quarters of respondents in this survey (76.8%) reported that they had no refrigerator thermometer; thus, the refrigeration temperature could not be monitored. In this respect, knowledge of the correct refrigeration temperature is of no benefit to respondents who have no means of monitoring it. The observed refrigerator temperature means varied between −1.7 and 11.8°C, with an average temperature of 5.4°C. Of the refrigerators surveyed, 59% had an average temperature higher than 5°C, and 6% had an average temperature higher than 10°C. A similar study in Northern Ireland reported mean temperature ranged from 0.8 to 12.6°C, with 71.3% over 5°C and 6% over 10°C *(15).* If food is held over time in temperatures conductive to bacterial growth, there is a potential risk in terms of food safety because it allows more rapid growth of spoilage microorganisms and the growth of food pathogens, if they are present *(23).* This is important at the domestic refrigeration stage, which can be the last line of defense in terms of controlling bacterial proliferation.

In general, the majority of respondents in this all-Ireland study did correctly identify occasions when hand washing is important in terms of good domestic food preparation practice, such as before meals (69.9%). However, this result is less satisfactory than in other countries. For example, Australian consumers scored higher (81.6%) on hand washing, reporting hand washing before meals. More significantly, the fact that more than 30% of those preparing food in Irish homes do not wash their hands at such times continues to present considerably increased risks to themselves and their families.

Respondents to this survey scored quite well (i.e., 64.6%) in terms of the need to wash hands after handling raw meat, which is better than in other similar studies. For example, only 53% of Australian consumers scored well in this area. One of the most worrying observations in this study was that less than half (49.6%) of respondents reported the importance of washing hands after using the toilet. The critical importance of fecal-to-oral transfer is well established in the epidemiology of pathogens, and such responses indicate the need for significantly greater education in this area. It has long been established that pets carry a range of human pathogens and can facilitate cross-contamination. Thus, the very low percentage of respondents (7%) who recognized the need to wash hands after contact with pets is of concern, especially because this percentage is so much lower than reported in other studies. In comparison, almost all survey respondents (99%) in New Zealand did consider hand washing important after touching a pet *(8).* This suggests that Irish consumers require significantly more information and education in relation to the role of domestic pets as significant sources of human pathogens *(9).* However, Ireland is not alone in this regard, because poor knowledge and practice in relation to pets as sources of human pathogens have been reported in other countries (e.g., Australia *(22)*). This suggestion is confirmed by the observation that more than half (52.4%) of respondents who had pets allowed their pet into the kitchen.

A considerable percentage of respondents did not use effective means of properly cleaning cutting boards (23%) and knives (24%) after cutting raw meat, leaving themselves and their families subject to significant risk of consuming cross-contaminated foods. Such cross-contamination in domestic kitchens is suggested to be responsible for 14% of all cases of food poisoning in the United Kingdom *(33).* Such undesirable results have also been reported in Australia, where similar percentages of consumers failed to clean utensils correctly after use with raw meat and vegetables *(23).* Such observations confirm the more general finding of a Ministry of Agriculture, Fisheries, and Food survey, which found that 70% of British consumers were unaware of the risks, potential, and nature of cross-contamination *(2).* Because it is currently impossible to prevent undesirable pathogens from entering the domestic kitchen on raw meat, vegetables, etc., considerable efforts could be required to improve consumer understanding and action in this area.

Irish consumers had a limited knowledge of food-associated pathogens. Although most respondents had heard of *Salmonella* (92.9%) and *E. coli* O157 (77%), less than half (45.2%) had heard of *L. monocytogenes,* and the other significant foodborne pathogens (*Campylobacter, B. cereus, S. aureus, C. perfringens, C. botulinum, Y. enterocolitica,* and viruses) were less well known (<20% awareness; Table 3). Overall, there was considerable ignorance regarding the association between pathogens and specific high-risk foods. This is in agreement with Scott *(35),* who reported that many British consumers were unaware of the link between foods, especially raw foods, and bacterial pathogens. Even the best scores of correct association were less than 50%. Thus, only 44% of respondents were able to associate *Salmonella* with eggs, 39% *E. coli* O157:H7 with beef, 33% *Yersinia* with pork, and 28% *Listeria* with soft cheeses. These exceptions probably relate to recent large or high-profile outbreaks involving those pathogens. In most other cases, correct associations were less frequent (i.e., <20%), with many scoring less than 10%.

The relatively strong recognition of *Salmonella* and its association with eggs is in agreement with Jay et al. *(23),* who reported *Salmonella* as the best known foodborne pathogen in a study of Australian consumers, although the degree of association was much higher in that study (96%).

Other, higher degrees of association between *Salmonella* and eggs have been reported; for example, Altekruse et al. *(1)* observed that 80.2% of U.S. respondents associated *Salmonella* with eggs. However, such patterns do not extend to other pathogens; for example, in this study, only 14% of respondents associated *C. botulinum* with canned foods, which is much lower than in the Australia (62%, *(23)*) or the U.S. (74.8%, *(1)*). Higher recognition in Australia and the United States might reflect the greater popularity of home canning of low-acid foods in these countries.

This study found that socioeconomic status and level of education were inversely associated with the incidence of pathogens and overall microbial numbers (TVCs) in domestic refrigerators. ABC1 consumers with a third-level qualification had higher incidences of pathogens, and higher TVCs in their refrigerators. Those with a third-level education or higher paid job might lack adequate food skills because of a lack of food handling experience *(38),* or they might follow different lifestyles, such as proportionally greater consumption of convenience foods *(25),* or have a lower aversion to risk-taking behaviors *(4, 24).*

Interestingly, consumers under 25 years of age were also more likely to have pathogens in their refrigerator. Griffith et al. *(18)* and Williamson et al. *(39)* reported a link between age and food hygiene, with older people more likely to properly store and cook food. Younger consumers often lack basic food handling and preparation skills because of changes in lifestyle and the increased consumption of convenience foods *(25).* For whatever reason, it is clear that younger consumers face higher risks of domestic foodborne illness. Thus, the findings of this study support Williamson et al. *(39)* in recommending a greater focus on food safety educational efforts for consumers under 35 years of age.

The hygiene status of refrigerators is indicated by TVC and TCC. The average TVC was 7.1 log CFU/cm^2 and varied between not detected and 9.56 log CFU/cm^2. Gorman et al. *(17)* similarly reported a TVC of 7 log CFU/cm^2 in domestic kitchens. The average TCC was 4.0 log CFU/cm^2 and varied between not detected and 6.43 log CFU/cm^2. In other studies, it was found that the kitchen environment was more heavily contaminated with coliforms than the bathroom *(30, 34).* This study shows that there is a wide range of undesirable bacteria and pathogens in domestic refrigerators. *S. aureus* was the most common pathogen found (41%), followed by *Salmonella* (7%), *L. monocytogenes* (6%), and *Y. enterocolitica* (2%). Other studies have also detected bacterial pathogens in the domestic kitchen environment, including *E. coli (37), Listeria* spp. *(7), L. monocytogenes (12, 36),* and *S. aureus (13).* The pathogens found in this study of domestic refrigerators could contaminate food directly or indirectly and pose an important risk to consumers in terms of food poisoning. Thus food safety knowledge with a focus on kitchen hygiene and prevention of cross-contamination is necessary if the scale and effect of domestic foodborne illness is to be reduced.

Although Irish consumers generally had limited knowledge of high-risk foods, those respondents who had better microbial knowledge were more likely to practice hygienic food storage and preparation and had lower TVCs and incidence of pathogens in their refrigerators. Furthermore, those households with ''cleaner'' refrigerators (i.e., lower TVCs) reported lower incidences of food poisoning within the last 12 months. This is in line with Woodburn and Raab *(40),* who reported that the ability to correctly identify foods associated with a specific pathogen was an important motivator for safe food preparation in U.S. homes. Overall, these findings are in agreement with Scott *(35)* and suggest that effective and appropriate food safety education can deliver significant reductions in the burden of foodborne illness among consumers.

The results of the food safety knowledge, microbial, and temperature surveys give cause for concern about consumer food storage and food preparation practices. Food safety agencies, such as the Food Safety Promotion Board on the island of Ireland should tailor the food hygiene message to educate consumers about bacterial pathogens and foods associated with them in order to motivate changes in cleaning, chilling, cross-contamination, and cooking in the domestic kitchen. This message should be targeted at younger audiences (<35 years), and parents should be reminded of their responsibility for teaching their children the fundamentals of food hygiene.

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