Microbiological Safety of Retail Vacuum-Packed and Modified-Atmosphere-Packed Cooked Meats at End of Shelf Life

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ABSTRACT

A study of retail modified-atmosphere-packed and vacuum-packed cooked ready-to-eat meats was undertaken from September through mid-November 2003 to determine the microbiological quality at the end of shelf life and to establish any risk factors in the production, storage, and display of this product. Examination of 2,981 samples using Microbiological Guidelines criteria revealed that 66% were of satisfactory or acceptable microbiology quality, 33% were of unsatisfactory quality mainly due to high aerobic colony counts and Enterobacteriaceae concentrations, and 1% were of unacceptable quality due to the presence of Listeria monocytogenes at 100 CFU/g or higher (27 samples; range of 10^2 to 10^6 CFU/g) and Campylobacter jejuni (1 sample), indicating a risk to health. All samples at the end of the shelf life had satisfactory (<20 CFU/g) or acceptable (<10^2 CFU/g) levels of Staphylococcus aureus and Clostridium perfringens, four samples (<1%) had unsatisfactory levels of Escherichia coli (range of 10^2 to 10^6 CFU/g) and 5.5% of the samples contained L. monocytogenes at <20 CFU/g (4.8%) or between 20 and 100 CFU/g (0.7%). More samples of chicken (45%; 224 of 495 samples), beef (43%; 160 of 371 samples), and turkey (41%; 219 of 523 samples) were of unsatisfactory or unacceptable quality compared with ham (23%; 317 of 1,351 samples) or pork (32%; 67 of 206 samples). Twelve different L. monocytogenes typing characters (serotype-amplified fragment length polymorphism type–phage type) were evaluated for isolates recovered from samples of unacceptable quality, and the 1/2-IX-NT type was recovered from almost half (48%) of these samples. Salmonella was not detected in any samples examined. Risk factors identified for cooked meats that were microbiologically contaminated more frequently included vacuum packaging, packaging on retail premises, slicing, temperature not monitored in display units, and no hazard analysis system in place. Results from this study also suggest that the shelf life assigned to some modified-atmosphere-packed and vacuum-packed meats may not be appropriate.

Prepackaged sliced meats make up a third of the United Kingdom sliced meat market, and ham is the most popular sliced meat, accounting for over half of United Kingdom sales (36). Most prepackaged sliced meats are purchased from multiple retailers (36), and market growth of retail sliced meats in the United Kingdom between 1999 and 2003 increased by 111% and was worth £570 million ($990 million) in 2003 (8). Modified atmosphere packaging (MAP) and vacuum packaging (VP) of sliced meats has become more common, and these products are increasingly popular because of consumer demand for fresher convenience foods that are safe, nutritional, and organoleptically pleasing and have longer shelf lives. VP is essentially the evacuation of air from a package that is then hermetically sealed. With MAP, air is removed and replaced with a strictly controlled gaseous mixture of carbon dioxide, oxygen, and/or nitrogen. A United Kingdom industry code of practice provides information on available VP and MAP methods (5).

Both packaging techniques have the potential to increase the shelf life of many chilled foods without adversely affecting the quality. Although changing the atmosphere may retard the growth of spoilage organisms, it also may allow growth of psychrotrophic pathogenic bacteria such as Clostridium botulinum and Listeria monocytogenes. The United Kingdom industry code of practice advises that the shelf life of VP-MAP cured uncured meats should not exceed 10 days at 3 to 8°C unless microbiological safety under extended storage conditions can be demonstrated. Cured meats such as ham typically have specific controlling factors (e.g., 3.5% salt, pH < 5, water activity < 0.97) and therefore may have a shelf life of more than 10 days (5). Temperature control regulations require that chilled VP-MAP foods, including cooked meats, be stored and displayed at or below 8°C in retail premises (14). However, manufacturers often use a storage temperature of less than 3°C during predistribution and generally recommend 5°C or less for domestic storage by the consumer (7). Refrigeration storage temperatures may therefore vary from predistribution, retail, and the consumer home.

Contaminated food is considered the main source of L. monocytogenes infections in humans, and contaminated cooked meats have been responsible for causing major outbreaks of L. monocytogenes infection in France, Norway, Australia, and the United States (6, 9, 18, 31, 40). Although listeriosis is a rare disease in the United Kingdom in contrast to infection caused by other major bacterial foodborne diseases, it remains a cause for concern because of the increased risk posed to vulnerable groups and the severity of
the disease (1). The importance of *L. monocytogenes* as predominantly a foodborne pathogen stems from its ability to grow at refrigeration temperatures. It also can colonize and become endemic in the food-processing environment, including in process equipment, with potential contamination of end products such as sliced meats (17, 20, 36, 38). With a growing demand for ready-to-eat products with an extended shelf life, this possibility for contamination is a serious challenge to the food industry and is of great concern. The European Commission regulation on microbiological criteria for foodstuffs states that *L. monocytogenes* should be below 10^2 CFU/g during the shelf life of ready-to-eat foods (12). Appropriate shelf lives and temperature controls are therefore paramount for the microbiological safety of VP-MAP cooked meats. The purpose of this study was to establish the microbiological quality of VP-MAP cooked ready-to-eat meats on sale in the United Kingdom at the end of the shelf life. The study also was designed to evaluate the effect of risk factors (e.g., type of packaging, packed on or off the premises, display and storage temperatures) on microbiological quality of these meats and to examine the extent to which retail premises complied with the legal requirements.

**MATERIALS AND METHODS**

**Sample collection.** A total of 2,981 VP-MAP cooked ready-to-eat meat samples collected from retail premises were examined at the end of shelf life between 1 September and 10 November 2003 by 34 laboratories across the United Kingdom: 27 Health Protection Agency (HPA)-HPA Collaborating Laboratories, 3 National Public Health Service Laboratories in Wales, 3 Public Analysts, and 1 National Health Service Laboratory. Samples (100 g) were collected and transported to laboratories by staff from 348 Environmental Health Departments, involving 52 Local Authority Food Liaison Groups, in accordance with the Food Law Code of Practice (16) and Local Authorities Co-ordinators of Regulatory Services guidance on microbiological food sampling (33). VP-MAP meats included in the study were those that were sliced wafer thin or were portions of meat. Information on samples and premises was obtained by observation and enquiry and recorded on a standard form. Additional information collected on packaged cooked meats included type, country of origin, packing details, display and storage temperatures, presence of a hazard analysis system, and the level of food hygiene training received by the manager. Food hygiene inspections of premises are carried out by environmental health officers to assess hygiene application of hazard analysis critical control point (HACCP) systems and compliance with public health protection aspects of food law (16). Environmental health officers consider the number of customers likely to be put at risk if there is a failure in food hygiene and safety procedures in a particular retail establishment and award a consumer-at-risk score accordingly. Scores range from 0 (very few customers at risk) to 15 (a substantial number of customers at risk) (16).

**Sample examination.** Upon receipt at the laboratory, samples were stored in a monitored laboratory refrigerator at 6 ± 2 °C until the end of shelf life (i.e., use-by date), whereupon samples were examined (4). Aerobic colony counts (ACC) and the concentration or presence of *Enterobacteriaceae, Escherichia coli, Clostridium perfringens, Salmonella, Campylobacter spp., Staphylococcus aureus,* and total *Listeria* spp. including *L. monocytogenes* were determined in accordance with HPA standard microbiological methods (22–30). Isolates of *L. monocytogenes* at 10^2 CFU/g or more were sent to the Food Safety Microbiology Laboratory (FSLM) at the HPA Centre for Infections for further characterization by serotyping, phage typing, and amplified fragment length polymorphism (AFLP) typing as described previously (10, 21, 34, 37, 39). Isolates of *Campylobacter* spp. were sent to the Laboratory of Enteropathogenic (LEP) at the HPA Centre for Infections for typing.

To improve the interpretation of the microbiological quality of cooked meats, the dominant microorganisms in samples with high ACCs were identified. For ham and tongue samples with ACCs of 10^7 CFU/g or more and for other meats (e.g., beef, pork, and poultry) with ACCs of 10^6 CFU/g or more, the dominant microorganisms were identified by using Gram stain, catalase, and oxidase tests. The percentage component of the ACC was reported for three groups: lactic acid bacteria (LAB; gram positive and catalase negative, i.e., lactobacilli and streptococci), gram-negative and oxidase-positive bacteria (e.g., *Pseudomonas* spp. and *Aeromonas*), and gram-negative and oxidase-negative bacteria (e.g., *Enterobacteriaceae* and *Acinetobacter*).

Microbiological results were compared with microbiological guidelines for the quality of some ready-to-eat foods sampled at the point of sale (Table 1) (19). For the purpose of this study, when an unsatisfactory ACC consisted predominantly of LAB it was classified as unsatisfactory only when concentrations exceeded 10^6 CFU/g. When gram-negative bacteria predominated, the ACC was deemed unsatisfactory when concentrations exceeded 10^7 CFU/g.

**Statistical analysis.** Descriptive and statistical analysis of the data were undertaken using Microsoft Excel version 9 (Microsoft, Redmond, Wash.) and Epi Info version 6.04d (Centers for Disease Control and Prevention, Atlanta, Ga.). Relative proportions were compared using chi-square and Fisher’s exact tests. A probability value of less than 5% was considered significant.

**RESULTS**

**Bacteria isolated from VP-MAP cooked meats.** Of the 2,981 samples examined, 1,362 were ham and tongue, and of these, 56% (757) had ACCs of 10^2 CFU/g or more. Of the 1,619 other meat samples, 65% (1,047) had ACCs higher than 10^6 CFU/g. *Enterobacteriaceae* were present at 10^4 CFU/g or more in 15% (445) of the samples (Table 2). *E. coli* was present at 10^2 CFU/g or more in 0.1% (4) of all meat samples. *S. aureus* and *C. perfringens* were present at 20 to <10^2 CFU/g in 0.3% (9) and 0.1% (4) of the samples, respectively. *Listeria* spp. (including *L. monocytogenes*) were detected in 6.4% (191) of the samples; in 1% (29) of these samples the concentration was 20 to <100 CFU/g, and in 1.4% (43) of these samples the concentration was 100 CFU/g or more. *L. monocytogenes* was detected in 4.8% (143) of the samples; in 0.7% (20) of these samples the concentration was 20 to <100 CFU/g, and in 0.9% (27) of these samples the concentration was 100 CFU/g or more (range, 1.0 × 10^2 to 2.4 × 10^6 CFU/g). Thirty-six of the 43 *Listeria* isolates recovered from samples with concentrations higher than 10^2 CFU/g were *Listeria innocua* (5 isolates: 2 from ham, 2 from beef, and 1 from chicken), *Listeria seeligeri* (2 isolates from ham), *Listeria welshimeri* (2 isolates: 1 from ham and 1 from pork), and *L. monocytogenes* (27 isolates: 22 of serotype 1/2, 2 of serotype 4b,
TABLE 1. Public Health Laboratory Service guidelines for the microbiological quality of some ready-to-eat foods sampled at the point of sale (19)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Satisfactory</th>
<th>Acceptable</th>
<th>Unsatisfactory</th>
<th>Unacceptable or potentially hazardous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic colony count</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All meats other than ham</td>
<td>&lt;10^5</td>
<td>10^5 to 10^6</td>
<td>≥10^6</td>
<td>NA^b</td>
</tr>
<tr>
<td>Ham and tongue</td>
<td>&lt;10^6</td>
<td>10^6 to 10^7</td>
<td>≥10^7</td>
<td>NA</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>&lt;10^2</td>
<td>10^2 to 10^4</td>
<td>≥10^4</td>
<td>NA</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>&lt;20</td>
<td>20 to &lt;10^2</td>
<td>≥10^2</td>
<td>NA</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>&lt;20</td>
<td>20 to &lt;10^2</td>
<td>10^2 to 10^4</td>
<td>≥10^4</td>
</tr>
<tr>
<td>Clostridium perfringens</td>
<td>&lt;20</td>
<td>20 to &lt;10^2</td>
<td>10^2 to 10^4</td>
<td>≥10^4</td>
</tr>
<tr>
<td>Listeria spp. (total)</td>
<td>&lt;20</td>
<td>20 to &lt;10^2</td>
<td>≥10^2</td>
<td>NA</td>
</tr>
<tr>
<td>L. monocytogenes</td>
<td>&lt;20</td>
<td>20 to &lt;10^2</td>
<td>NA</td>
<td>≥10^2</td>
</tr>
<tr>
<td>Campylobacter spp.</td>
<td>Not detected in 25 g</td>
<td></td>
<td></td>
<td>Detected in 25 g</td>
</tr>
<tr>
<td>Salmonella</td>
<td>Not detected in 25 g</td>
<td></td>
<td></td>
<td>Detected in 25 g</td>
</tr>
</tbody>
</table>

^a When an unsatisfactory aerobic colony count (ACC) consisted predominantly of lactic acid bacteria, it was classified as unsatisfactory only when the concentration exceeded 10^8 CFU/g. When gram-negative bacteria predominated, the ACC was deemed unsatisfactory when the concentration exceeded 10^7 CFU/g.

^b NA, not applicable.

and 3 nontype [NT]) (Table 3). Campylobacter spp. (C. jejuni HS44 PT70) was detected in 0.03% of the samples (one turkey sample). Salmonella was not detected in any of the samples examined.

High ACCs from 1,804 samples were examined to identify the bacteria that predominated. The majority of these samples (88%; 1,587 samples) contained LAB as 100% of the ACC, 2% (40) of the high-ACC samples contained gram-negative, oxidase-positive bacteria, and 10% (177) of the samples contained gram-negative, oxidase-negative bacteria.

L. monocytogenes isolate types in VP-MAP cooked meats. Twelve different L. monocytogenes typing characters (serotype–AFLP–phage type) were used to classify samples with 10^2 CFU/g or higher, i.e., samples of unacceptable microbiological quality (Table 3). The 1/2-IX-NT type was identified in almost half of them (48%; 12 of the 25 samples). Approximately half of these samples (48%; 12 samples) with unacceptable L. monocytogenes concentrations were obtained from meats produced by manufacturer A, with the typing character 1/2-IX-NT predominating in 8 (67%) of the samples. These adverse results were reported to the appropriate food authority, manufacturer, and the Food Standards Agency, and full investigations were undertaken.

Microbiological quality of VP-MAP cooked meats. Based on microbiological guidelines for some ready-to-eat foods sampled at the point of sale (Table 1) (19), 46% of the 2,981 VP-MAP meat samples were of satisfactory microbiological quality, 20% were acceptable, and 33% were unsatisfactory. However, 1% (28) of these samples were of unacceptable microbiology quality because of the presence of L. monocytogenes at 10^2 CFU/g or more (27 samples) and the presence of Campylobacter jejuni (1 sample).

Product characteristics in relation to microbiological quality. Almost half (45%; 1,351) of the 2,981 VP-MAP meat samples collected were ham, followed by turkey (18%), chicken (17%), beef (12%), pork (7%), and other meats such as lamb, duck, and haslet (English meat loaf that has been cooked and sliced and is ready to eat) (1%) (Table 4). Significantly more samples of chicken (45%; 224 of 495 samples), beef (43%; 160 of 371 samples), and turkey (41%; 219 of 523 samples) were of unsatisfactory or unacceptable quality compared with ham (23%; 317 of 1,351 samples) or pork (32%; 67 of 206 samples) (P = 0.0001).

More than two-thirds of samples collected were sliced meat (67%; 1,992 samples), 18% (549 samples) were wafer-thin meats, and 4% (122 samples) were meat portions (e.g., chunks, shavings, or strips), and for 11% (318 samples) this information was not recorded (Table 4). The proportion of sliced, portioned, and other meat products of unsatisfactory or unacceptable microbiological quality was higher (36, 37, and 33%, respectively) when compared with wafer-thin meat (26%). This finding was only significant when comparing sliced meat and wafer-thin meat (P = 0.0001).

Most samples (80%; 2,391) were MAP, 18% (525 samples) were VP, and for 2% (65 samples) this information was not recorded (Table 4). Significantly more VP samples (43%; 228 of 525 samples) were of unsatisfactory or unacceptable microbiological quality compared with MAP samples (31%; 751) (P = 0.0001).

The majority of cooked meat samples (95%; 2,844) were not packaged on the premises, 4% (113 samples) were packaged on the premises, and for 1% (24 samples) this information was not recorded (Table 4). Although the total numbers were low, more samples packaged on the premises were of unsatisfactory or unacceptable microbiological
TABLE 2. Microbiological results of 2,981 VP-MAP ready-to-eat meat samples at end of shelf life

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>No. of samples in which contamination was:</th>
<th>Detected at (CFU/g):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detected in 25 g</td>
<td>&lt;10 to &lt;20</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Aerobic colony count</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td><em>Enterobacteriaceae</em></td>
<td></td>
<td>1,994c</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td></td>
<td>2,952d</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td></td>
<td>2,951d</td>
</tr>
<tr>
<td><em>Clostridium perfringens</em></td>
<td></td>
<td>2,948c</td>
</tr>
<tr>
<td><em>Listeria</em> spp. (total)</td>
<td></td>
<td>2,717</td>
</tr>
<tr>
<td><em>L. monocytogenes</em></td>
<td></td>
<td>190</td>
</tr>
<tr>
<td><em>Campylobacter</em> spp.</td>
<td></td>
<td>2,953</td>
</tr>
<tr>
<td><em>Salmonella</em></td>
<td></td>
<td>2,971</td>
</tr>
</tbody>
</table>

nd, not detected.
ne, not examined (full set of microbiological examinations not performed on sample because of insufficient sample).
Lower limit of detection was 10 CFU/g.
Lower limit of detection was 20 CFU/g.

TABLE 3. Typing characters of *L. monocytogenes* isolated from 25 samples of VP-MAP cooked meat of unacceptable microbiological quality at end of shelf life

<table>
<thead>
<tr>
<th>Typing character (serotype–AFLP–phage type)</th>
<th>No. of samples</th>
<th>Meat type (no. of samples)</th>
<th>Manufacturer</th>
<th>Country of origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2-IX-NTd</td>
<td>12</td>
<td>Beef (1e)</td>
<td>Not specified</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chicken (3f)</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>No marking on package</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ham (5)</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turkey (3)</td>
<td>B</td>
<td>No marking on package</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2-II-Y</td>
<td>1</td>
<td>Beef</td>
<td>B</td>
<td>No marking on package</td>
</tr>
<tr>
<td>1/2-VII-NT</td>
<td>1</td>
<td>Chicken</td>
<td>F</td>
<td>UK</td>
</tr>
<tr>
<td>1/2-XI-NT</td>
<td>1</td>
<td>Turkey</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td>4b-V-A</td>
<td>1</td>
<td>Corned beeff</td>
<td>H</td>
<td>No marking on package</td>
</tr>
<tr>
<td>4b-II-NT</td>
<td>1</td>
<td>Beef</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>1/2-II-Z</td>
<td>3</td>
<td>Beef (1)</td>
<td>E</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ham (2)</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2-IX-Y</td>
<td>1</td>
<td>Turkey</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td>1/2-IX-VV</td>
<td>1</td>
<td>Corned beef</td>
<td>J</td>
<td>No marking on package</td>
</tr>
<tr>
<td>1/2-II-NT</td>
<td>1</td>
<td>Ham</td>
<td>C</td>
<td>UK</td>
</tr>
<tr>
<td>NT-XI-NT</td>
<td>1</td>
<td>Chicken</td>
<td>A</td>
<td>UK</td>
</tr>
<tr>
<td>1/2-NT-WW</td>
<td>1</td>
<td>Ham</td>
<td>D</td>
<td>No marking on package</td>
</tr>
</tbody>
</table>

a AFLP, amplified fragment length polymorphism.
b Two isolates were not typed.
c MAP meats unless stated.
d NT, nontypeable.
e Vacuum packed.
f One sample of chicken was vacuum packed.
TABLE 4. **Microbiological quality of VP-MAP meats**

<table>
<thead>
<tr>
<th>Product</th>
<th>No. (%) of samples of unsatisfactory or unacceptable quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of meat</td>
<td>No. (%)</td>
</tr>
<tr>
<td>Ham</td>
<td>1,351 (45) 317 (23)</td>
</tr>
<tr>
<td>Turkey</td>
<td>523 (18) 219 (41)</td>
</tr>
<tr>
<td>Chicken</td>
<td>495 (17) 224 (45)</td>
</tr>
<tr>
<td>Beef</td>
<td>371 (12) 160 (43)</td>
</tr>
<tr>
<td>Pork</td>
<td>206 (7) 67 (32)</td>
</tr>
<tr>
<td>Other (e.g., haslet, lamb, or duck)</td>
<td>35 (1) 13 (37)</td>
</tr>
<tr>
<td>Type of sample collected</td>
<td></td>
</tr>
<tr>
<td>Sliced</td>
<td>1,992 (67) 712 (36)</td>
</tr>
<tr>
<td>Wafer thin (cut very thinly)</td>
<td>549 (18) 142 (26)</td>
</tr>
<tr>
<td>Portions (e.g., bite-size chunks, shavings, or strips)</td>
<td>122 (4) 43 (35)</td>
</tr>
<tr>
<td>Not recorded</td>
<td>318 (11) 103 (32)</td>
</tr>
<tr>
<td>Type of packaging</td>
<td></td>
</tr>
<tr>
<td>MAP</td>
<td>2,391 (80) 751 (31)</td>
</tr>
<tr>
<td>VP</td>
<td>525 (18) 228 (43)</td>
</tr>
<tr>
<td>Not recorded</td>
<td>65 (2) 21 (32)</td>
</tr>
<tr>
<td>Packed on the premises</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2,844 (95) 934 (32)</td>
</tr>
<tr>
<td>No</td>
<td>113 (4) 54 (48)</td>
</tr>
<tr>
<td>Not recorded</td>
<td>24 (1) 12 (50)</td>
</tr>
<tr>
<td>Packed more than once</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>119 (4) 45 (38)</td>
</tr>
<tr>
<td>No</td>
<td>676 (22) 243 (36)</td>
</tr>
<tr>
<td>Not recorded</td>
<td>2,186 (74) 712 (33)</td>
</tr>
<tr>
<td>Organic meat&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>27 (1) 4 (15)</td>
</tr>
<tr>
<td>No</td>
<td>2,871 (96) 972 (33)</td>
</tr>
<tr>
<td>Not recorded</td>
<td>83 (3) 24 (29)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Meat samples were considered organic when they carried a designated “organic” sign or number. The word organic may be applied only to products that have been grown, processed, and packaged in accordance with the requirements of the European Community Council Regulation 2092/91 as amended by Regulation EC (No.) 780/2006/13.

More than once in their history as a ready-to-eat product, 22% (676 samples) were not, but for 74% (2,186 samples) this information was not known (Table 4). Proportionally, the number of unsatisfactory or unacceptable VP-MAP meat samples packed more than once was higher (38%; 45 of 119 samples) than the number in those categories that were not repackaged (36%; 243 of 676 samples); however, this difference was not significant.

Most (96%; 2,871) of the 2,981 samples were not organic, 1% (27) were, and for 3% (83 samples) this information was not recorded (Table 4). The proportion of non-organic samples of unsatisfactory or unacceptable microbiological quality was higher (33%) than that for organic meats (15%); however, this difference was not significant.

Approximately two-thirds (67%; 1,990) of the 2,981 samples were recorded as having a United Kingdom origin, 12% (360 samples) were produced outside the United Kingdom (i.e., in other EU or non-EU countries), and for 21% (631 samples) this information was not recorded. There was no significant difference in the proportion of meat samples of unsatisfactory or unacceptable microbiological quality when comparing samples that were imported (30%) with those that were not (35%).

**Meat storage and display temperature in relation to microbiological quality.** Most (97%) of the samples were stored in a visually clean display area, as judged by the sampling officer, and most (87%) were displayed in upright units with shelves (Table 5). There was no significant differences in the proportion of unsatisfactory or unacceptable samples based on visual cleanliness or the type of display unit (Table 5).

At the time of sampling, the air temperature around VP-MAP meat samples on display was at or below 5°C for over two-thirds (68%) of samples and was above 5°C or at or below 8°C for another 23% of the samples (Table 5). The storage temperature of packaged meat on display had no significant effect on the microbiological quality of the samples with regard to unsatisfactory or unacceptable microbiological quality (Table 5). Most (93%) of the samples had storage temperature information present on the packaging, of which 61% advised to keep the product refrigerated and 32% specified a refrigeration temperature (Table 5). Where a particular storage temperature was provided on the packaging, 75% specified storage between 0 and 5°C, 15% specified between 2 and 5°C, 5% specified less than 7°C, and 5% specified less than 8°C. For the packaged samples that had an air temperature at or below 5°C on display, 30% (621 of 2,027 samples) were labeled on the packaging with a specified storage temperature: 90% (561 of 621) with 0 to 5°C and 10% (60 of 621) with 2 to 8°C. Most samples (62%; 1,249 of 2,027) were labeled with advice to keep the product refrigerated. Of the samples displayed at an air temperature above 5°C and at or below 8°C, one third (33%; 232 of 685 samples) had packaging labeling listing a specified storage temperature: 62% (143 of 232) with 0 to 5°C and 38% (89 of 232) with 2 to 8°C. Most samples (59%; 406 of 685) were labeled with advice to keep the product refrigerated.
Most (93%) of the retailers monitored the temperature of the display unit: 44% used a thermometer in the unit, 34% used a link to a local or remote computer, and 22% used a temperature probe (Table 5). A higher proportion of the samples from display units where temperature was not monitored were of unsatisfactory or unacceptable quality (38%) compared with samples from units where temperature was monitored (33%), although this difference was not significant. In display units where temperature was monitored, more samples from units where a temperature probe was used were of unsatisfactory or unacceptable quality (39%) compared with those samples from units where temperature was monitored by a link to a computer (35%) or by a thermometer in the unit (36%) (Table 5).

**Premises information in relation to microbiological quality.** Most of the 2,981 samples were collected from supermarkets (61%; 1,822 samples) and convenience or corner shops (36%; 909 samples) (Table 6). The proportions of VP-MAP meat samples of unsatisfactory or unacceptable microbiological quality that came from conve-

### TABLE 5. Microbiological quality of VP-MAP meats in relation to their display and storage

<table>
<thead>
<tr>
<th>Storage and display details</th>
<th>No. (%) of samples</th>
<th>No. (%) of samples of unsatisfactory or unacceptable quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Display area visually clean</strong></td>
<td>Yes</td>
<td>2,883 (97)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>39 (1)</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>59 (2)</td>
</tr>
<tr>
<td><strong>Type of display unit</strong></td>
<td>Upright with shelves</td>
<td>2,604 (87)</td>
</tr>
<tr>
<td></td>
<td>Upright with hooks</td>
<td>137 (4)</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>72 (2)</td>
</tr>
<tr>
<td></td>
<td>Other (e.g., flat units, wire racks, boxes)</td>
<td>107 (3)</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>61 (2)</td>
</tr>
<tr>
<td><strong>Storage temperature on package</strong></td>
<td>Keep refrigerated</td>
<td>1,806 (61)</td>
</tr>
<tr>
<td></td>
<td>No temperature indicated</td>
<td>145 (5)</td>
</tr>
<tr>
<td></td>
<td>Temperature specified</td>
<td>953 (32)</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>77 (2)</td>
</tr>
<tr>
<td><strong>Air temperature around packaged meat on display</strong></td>
<td>&lt;5°C</td>
<td>2,030 (68)</td>
</tr>
<tr>
<td></td>
<td>&gt;5°C to ≤8°C</td>
<td>685 (23)</td>
</tr>
<tr>
<td></td>
<td>&gt;8°C</td>
<td>160 (5)</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>106 (4)</td>
</tr>
<tr>
<td><strong>Temperature of display unit monitored by retailer</strong></td>
<td>Yes</td>
<td>2,752 (93)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>103 (3)</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>126 (4)</td>
</tr>
<tr>
<td><strong>Monitoring of temperature of display unit (n = 2,752)</strong></td>
<td>Link to local or remote computer</td>
<td>931 (34)</td>
</tr>
<tr>
<td></td>
<td>Thermometer in unit</td>
<td>1,211 (44)</td>
</tr>
<tr>
<td></td>
<td>Temperature probe</td>
<td>610 (22)</td>
</tr>
</tbody>
</table>

### TABLE 6. Microbiological quality of VP-MAP meats in relation to premises details

<table>
<thead>
<tr>
<th>Premises details</th>
<th>Total samples</th>
<th>No. (%) of samples of unsatisfactory or unacceptable quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Premises type</strong></td>
<td>Supermarket</td>
<td>1,822</td>
</tr>
<tr>
<td></td>
<td>Convenience mart or corner shop</td>
<td>909</td>
</tr>
<tr>
<td></td>
<td>Licensed butcher</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Delicatessen</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Greengrocer</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Nonlicensed butcher</td>
<td>3</td>
</tr>
<tr>
<td><strong>Consumer-at-risk category</strong></td>
<td>0 (very few customers)</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>5 (few customers)</td>
<td>1,792</td>
</tr>
<tr>
<td></td>
<td>10 (many customers)</td>
<td>706</td>
</tr>
<tr>
<td></td>
<td>15 (very many customers)</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>415</td>
</tr>
<tr>
<td><strong>Hazard analysis system</strong></td>
<td>In place and documented</td>
<td>1,877</td>
</tr>
<tr>
<td></td>
<td>In place and undocumented</td>
<td>337</td>
</tr>
<tr>
<td></td>
<td>In place; documentation status not recorded</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Not in place</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>Not recorded</td>
<td>279</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Management food hygiene training</th>
<th>Total samples</th>
<th>No. (%) of samples of unsatisfactory or unacceptable quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Received training and attended</strong></td>
<td>2,320/2,981</td>
<td>78</td>
</tr>
<tr>
<td><strong>Basic 6-h course</strong></td>
<td>1,441/2,320</td>
<td>62</td>
</tr>
<tr>
<td><strong>Intermediate course</strong></td>
<td>509/2,320</td>
<td>22</td>
</tr>
<tr>
<td><strong>Advanced course</strong></td>
<td>92/2,320</td>
<td>4</td>
</tr>
<tr>
<td><strong>Other recognized course</strong></td>
<td>150/2,320</td>
<td>6</td>
</tr>
<tr>
<td><strong>Not specified</strong></td>
<td>128/2,320</td>
<td>6</td>
</tr>
<tr>
<td><strong>No training</strong></td>
<td>395/2,981</td>
<td>13</td>
</tr>
<tr>
<td><strong>Not recorded</strong></td>
<td>266/2,981</td>
<td>9</td>
</tr>
</tbody>
</table>

*Businesses supplying less than 20 consumers each day.*

*Businesses whose customers are likely to be living or working in the local area, e.g., a shop on a main street.*

*Businesses serving a large number of customers, including many from outside the local area, e.g., superstore or hypermarket.*

*Manufacturers or retailers of food that is distributed nationally or internationally.*
nience or corner shops (35%), delicatessens (40%), market stalls (42%), greengrocers (52%), licensed butchers (53%), and other premises (42%) were higher than that proportion of samples collected from supermarkets (31%). These differences were significant only when comparing samples from convenience shops ($P = 0.0302$), licensed butchers ($P = 0.0001$), and greengrocers ($P = 0.0405$) with those from supermarkets.

Most of the samples were obtained from premises of consumer-at-risk categories 5 (few customers, 60%) and 10 (intermediate numbers of customers, 23%) (Table 6). In proportion, more samples of unsatisfactory or unacceptable microbiological quality were collected from premises with consumer-at-risk scores of 0 to 5 (very few to few customers, 34%) compared with those collected from premises with scores of 10 to 15 (many to very many customers, 30%) (Table 6).

Almost two-thirds (63%) of the premises visited had a documented hazard analysis system, and a further 11% had an undocumented hazard analysis system (Table 6). Samples collected from premises without a hazard analysis system in place were more likely to be of unsatisfactory or unacceptable microbiological quality (36%) compared with those samples collected from premises where a hazard analysis system was in place (33%) (Table 6).

Over three quarters (78%) of samples were collected from premises whose managers had received food hygiene training (Table 6). No significant difference in the number of samples that were of unsatisfactory or unacceptable microbiological quality was found between premises with managers that had received this training and premises whose managers had not been trained (Table 6).

**DISCUSSION**

In this study, 66% of MAP-VP meat samples at the end of shelf life were of satisfactory or acceptable quality, 33% were of unsatisfactory quality, and 1% were of unacceptable quality or were a potential risk to public health according to published microbiological guidelines (19). Unsatisfactory microbiological results were mainly due to high ACCs for LAB ($\geq 10^8$ CFU/g) and/or high Enterobacteriaceae concentrations ($> 10^4$ CFU/g). High ACCs and Enterobacteriaceae concentrations can indicate that the cooking process was inadequate, that post-processing contamination had occurred, that the length of time and temperature control in storage facilities was inadequate to prevent bacterial growth, that the shelf life assigned was not appropriate, or that a combination of these factors was involved.

In a previous United Kingdom study conducted in 1995 (36), a lower proportion (10%) of prepacked sliced cooked meats at the end of shelf life had LAB at or more than $10^8$ CFU/g, and microbial growth of spoilage organisms such as LAB and Enterobacteriaceae occurred during storage after slicing and packaging. Therefore, it is important to minimize postprocessing contamination and enforce strict temperature control throughout storage and during retail sale to minimize any proliferation of these organisms in food.

In this study, the pathogens *L. monocytogenes*, *S. aureus*, and *C. perfringens* were detected in 190 (6.4%), 9 (0.3%), and 4 (0.1%) of the samples, respectively. *Campylobacter* spp. were detected from one sample. In an earlier United Kingdom study of prepacked sliced meats tested at the end of shelf life (36), 5.3% of samples contained *L. monocytogenes*, 1% contained *S. aureus*, 0.2% contained *C. perfringens*, and one sample contained *Campylobacter* spp. In three regional studies in England conducted during 2002, a similar prevalence of *L. monocytogenes* was found in MAP-VP sliced meats at the end of shelf life (5.0 to 5.3%) (3, 41, 42). The prevalence of *L. monocytogenes* at unacceptable concentrations in MAP-VP meats in the current study (1%) was comparable to that previously found in England (0.6 to 1.7%) (3, 36, 41, 42) and Denmark (1.4%) (38) but was higher than that in Ireland (0%) (17). The presence of these organisms, and in particular the presence of *L. monocytogenes* at unacceptable concentrations, demonstrates the need for good hygiene practices during processing to prevent contamination and emphasizes the importance of strict temperature controls during the shelf life of VP-MAP ready-to-eat sliced meats. The predominant typing character (1/2-IX-NT) of *L. monocytogenes* recovered from VP-MAP meat samples of unacceptable microbiological quality in this study also was identified in four human cases of *L. monocytogenes* infection during 2003 (35).

A greater proportion of VP meats at the end of shelf life were of unsatisfactory or unacceptable microbiological quality (43%) compared with MAP meats (31%). Those meats packed on the retail premises had a higher proportion of unsatisfactory and/or unacceptable samples (48%) compared with those that were not packed on the premises (32%). Unsatisfactory or unacceptable microbiological quality of meats in a United Kingdom 2002 study reported by Elson et al. (11) also was associated with meat cooked or sliced elsewhere. Gombas et al. (20) reported a higher incidence of *L. monocytogenes* in meats that were packed on the premises compared with meats packed elsewhere in the United States during 2002. Additionally, a higher proportion of meats packed on the premises with a shelf life of 10 days or more and where a risk assessment (e.g., covering HACCP systems, heat treatment, and storage life, taking into account the likely contamination and the survival and growth characteristics of those organisms concerned) had not been conducted to assess product shelf life were of unsatisfactory and/or unacceptable microbiological quality. In relation to the potential for growth of psychrotrophic *C. botulinum* during storage, the United Kingdom industry code of practice advises that the shelf life of a chilled MAP-VP food (i.e., stored at 3 to 8°C) should not exceed 10 days unless its safety under expected storage conditions can be demonstrated (2, 5, 15). Due attention also should be given to the effect of storage on other food pathogens, such as *L. monocytogenes*, which would also be relevant to the subsequent shelf life (5). The influence of packaging type and place of packaging on *L. monocytogenes* contamination of MAP-VP meats warrants further investigation.

Slicing is a postcooking process that poses a microbiological risk because of the potential for recontamination...
via the slicing blade. In recent years, wafer-thin sliced meats have been introduced onto the market. This product is sliced thinner than traditional sliced meats. In this study, slice width had an effect on microbiological quality, with more sliced meat samples of unsatisfactory and/or unacceptable quality (36%) compared with wafer-thin meat samples (26%). This difference may be due to differences in the way the meat is sliced and the way the equipment is cleaned. Cooked meat slicing machines can be a source of contamination and cross-contamination when they are incorrectly cleaned (11, 32).

Samples collected from display units where temperature was not monitored were more likely to be of unsatisfactory or unacceptable quality (38%) than were samples from units where temperature was monitored (33%). In conjunction with implementing HACCP principles as the basis for the retailer product safety management systems, correct maintenance of storage temperature is vital for ensuring the microbiological safety and stability of chilled food products. The performance of the proposed distribution chain should therefore be validated and monitored and taken into account when specifying shelf life of the product (7).

The long shelf life of VP-MAP meats may allow the population of \emph{L. monocytogenes} to reach unacceptable concentrations, i.e., more than 100 CFU/g. Efforts must be made to ensure that the product does not become contaminated before final packaging or the shelf life should be reduced so that recontamination does not result in the growth of the organism to high numbers. Where the product is sold through other outlets, the performance of the proposed distribution chain should be taken into account when specifying the shelf life of the product (7), in particular considering that refrigeration storage temperatures will vary at predistribution locations, retail premises, and the consumer’s home.

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