Incidents of food poisoning and food-borne diseases from 'new' or 'unexpected' causes: can they be prevented?

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Summary This paper presents a survey of selected incidents of food poisoning and food-borne disease and examines the lessons that can be learned about the extent of the success of food hygiene and quality assurance approaches.

Keywords Food-borne disease, food hygiene, food poisoning, HACCP, ISO 9001/9002.

Introduction

This review presents a selective survey of incidents of food poisoning and food-borne disease, with a view to the lessons that can be learned about the extent of the success of food hygiene and quality assurance approaches and the possible ways of taking precautions against the unexpected. Further papers in this issue by Dalsgaard and by Blanchfield discuss specific real and potential hazards. In the case of some of the *Vibrio* species mentioned by Dalsgaard, the hazard is real and serious. For example, *V. vulnificus* infections from shellfish (Huq *et al.*, 1980) can be rapidly fatal (Blake, Weaver & Hollis, 1980). In the case of bovine spongiform encephalopathy (BSE), discussed by Blanchfield, the hazard of the BSE prion being a possible cause of new variant Creutzfeldt–Jakob disease is still somewhat in question.

Microbiological criteria and food hygiene in a legal context

The overall incidence of food poisoning and food-borne disease in many countries has shown no marked tendency to decline in recent decades, in spite of the increase in food legislation. For example, the introduction of the Food Safety Act 1990 (Anonymous, 1990) in the UK was not followed by any substantial or sustained decrease in *Salmonella* food poisoning. The microbiological examination of end-products to determine conformance to an end-product specification (i.e. microbiological criteria) is often used, particularly to examine foods moving in international trade, because an importing country may not know whether incoming batches of food have been produced in good hygienic conditions. It is obviously important to use such examinations against criteria that have international recognition, so as to be in line with the General Agreement on Tariffs and Trade (GATT) Uruguay Round Agreement on the Application of Sanitary and Phytosanitary Measures (ICMSF, 1997). In recent years, member states of the EU have been introducing detailed microbiological criteria into their food legislation. Examples are the UK's Dairy Products (Hygiene) Regulations 1995 (Anonymous, 1995a) and Minced Meat and Meat Preparations (Hygiene) Regulations 1995 (Anonymous, 1995b). However, the 100% destructive nature of current microbiological analyses means that end-product testing for conformance to such criteria provides only limited protection to the consumer against food poisoning or food-borne disease. Far better quality assurance is provided by requiring a food busi-

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ness to use a quality management system involving Hazard Analysis Critical Control Point (HACCP) evaluations (see, for example, Harrigan & Park, 1991; Mortimore & Wallace, 1994). In this context, microbiological criteria can be used for setting critical limits in HACCP systems and in the verification of the HACCP plans (IFST, 1997). Although HACCP plans have been used around the world since their inception in the US in the 1960s (Bauman, 1994), it is only relatively recently that a requirement for a food business to have a HACCP scheme in place has been introduced into legislation.

In the US, the Food and Drug Administration is starting to require food companies to use a HACCP approach. Appropriate regulations for seafood processing were proposed in 1995 (Anonymous, 1995c), and in 1997 implementation began of the US Department of Agriculture Food Safety and Inspection Service's final rule on Pathogen Reduction and Hazard Analysis and Critical Control Points. Similarly, in Europe, Article 3 of the EC directive on hygiene of foodstuffs (EC, 1993) resulted in member states incorporating into their food hygiene legislation requirements for HACCP evaluations by food producers, caterers and retailers [see, for example, the UK's Food Hygiene (General Food Hygiene) Regulations (Anonymous, 1995d)].

Better use of HACCP could help to avoid outbreaks associated with pathogens difficult to detect in the food involved. For example, an outbreak of hepatitis A infection was found to involve bread and bakery goods – certainly an unexpected vehicle (Warburton *et al.*, 1991). Investigation of the outbreak led to the conclusion that the bread had been contaminated by faecal contamination of a worker's hands that had been inadequately washed because of the presence of painful skin lesions. Thus, the outbreak could have been avoided by the wearing of disposable gloves or the use of tongs to move or serve the bakery goods.

Adoption of a HACCP scheme *should* provide assurance of a specified safe product, and operating the HACCP scheme within a quality management system certificated to ISO 9001 could then provide assurance that a safe product will be consistently produced (Harrigan, 1993; Mortimore & Wallace, 1994). However, success of the HACCP scheme depends on the HACCP evaluation being performed by a team that includes people with a sufficient and appropriate knowledge and understanding of microbial ecology and microbiological principles. Although microbiological analyses are of limited value when merely applied for the purpose of determining conformance of batches of product to microbiological criteria, they are of much greater value when used to validate and verify the monitoring procedures applied to the critical control points (Harrigan, 1998).

Once a particular pathogen–food combination has been identified as a hazard, official intervention, application of specific HACCP procedures by food businesses, and public education programmes may all play an important part in dealing with the problem. For example, after *Listeria monocytogenes* in salads such as coleslaw (Schlech *et al.*, 1983), soft cheeses (Linnan *et al.*, 1988) and meat pâté (McLauchlin *et al.*, 1991) was identified as a potentially severe hazard, particularly for pregnant women (McLauchlin, 1990), a combination of all the measures mentioned led to simultaneous reductions in the detection rates for *L. monocytogenes* in the target products and in the incidence of human listeriosis. Unfortunately, sometimes an outbreak may occur even when good HACCP procedures and Codes of Practice are being followed in the food plant. When Fleming and colleagues (1985) investigated an outbreak of listeriosis caused by pasteurized milk, they determined that the milk was being pasteurized to the legal requirement, that there were *no* faults detectable in hygienic precautions, process monitoring, keeping of records of critical control point (CCP) monitoring (e.g. phosphatase test results), or other aspects of production in the food plant. However, four cases of bovine listeriotic encephalitis had been diagnosed in dairy cattle on farms supplying milk to the dairy, and it was concluded that although post-pasteurization contamination could not be completely excluded, it was more likely that the normal, legally required, time–temperature combinations for pasteurization are insufficient to kill a high concentration of *L. monocytogenes* such as might derive from cows with a *L. monocytogenes* bacteraemia. This demonstrates the importance of extending the HACCP system back to the primary production unit (in this case the dairy farm). Further

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examples illustrating the importance of applying HACCP right through from farm to consumer will be given later.

Lessons to be learned from the *Salmonella enteritidis* PT4 story

The legal interpretation of a requirement for a food business to operate an effective HACCP system must surely be based on reasonableness and justice. The tremendous problems presented by *Salmonella enteritidis* PT4 in the UK and a number of other countries, from the beginning of the 1980s to the present day, illustrate some of the difficulties in developing appropriate food safety legislation. The appearance and spread of a *Salmonella* capable of easy transovarian infection of the interior of the hen egg was sudden, but perhaps could have been predicted. *Salmonella gallinarum* and *S. pullorum* were already known to be capable of transovarian transmission – it was our good fortune that these serovars have a very low infectivity for human beings.

Before the spread of *S. enteritidis* PT4 in the poultry flocks, *Salmonella* contamination of eggs was usually restricted to the outside surface of the shells. In these circumstances, a whole range of control measures could be adopted to minimize the risk from eggs used in food manufacturing and catering. The concentration of salmonellae found in broken-out egg would be relatively low, unless the egg was subject to temperature abuse. The hazard presented by bulk egg used in food manufacturing and bulk catering (e.g. for centralized production of precooked omelette etc.) could be controlled by pasteurization, and this was required by the Liquid Egg (Pasteurisation) Regulations 1963 (Anonymous, 1963), now replaced by the Egg Products Regulations 1993 (Anonymous, 1993). Use of shell eggs for catering purposes (boiled eggs, fried eggs, omelettes, soufflés, etc.) would offer little risk as long as eggs broken-out were used immediately, and the dishes were consumed immediately or were kept refrigerated for a short time before consumption. However, as soon as *S. enteritidis* PT4 put in an appearance, the situation changed.

The presence of *S. enteritidis* PT4 *inside* the shell eggs, and the absence of refrigeration from the time of laying until the time the shell eggs were used, permits large numbers of the salmonellae to build up in older eggs in which the bacteriostatic properties of the albumen have diminished (ACMSF, 1993). Humphrey & Whitehead (1993) found that this could occur after storage for 6–10 days at ambient temperatures. Counts of 10^8–10^{11} per gram of egg could be achieved during such multiplication (Humphrey *et al.*, 1989). Loss of the bacteriostatic character of the albumen was retarded by refrigeration. Significantly, Humphrey & Whitehead (1993) also found that in a small proportion of eggs, *S. enteritidis* could multiply rapidly in the albumen, irrespective of the age of the egg. These findings suggest very strongly indeed that legislation should require shell eggs to be subjected to refrigeration from the time of laying until the time of use. Not only are shell eggs distributed and sold without the benefit of a continuous cold chain, but it was found (ACMSF, 1993) that bulk-packed shell eggs supplied to caterers did not necessarily carry date-marking.

Infection of a person can result from the consumption of a single egg or part of an egg that has not been heat-treated sufficiently to destroy any salmonellae present. A whole range of egg-containing dishes receive very light heat treatments – soft-boiled eggs, fried eggs, omelettes, scrambled eggs, soufflés, meringues and sponge cakes. Infective doses of *S. enteritidis* PT4 can remain after boiling eggs for 9–10 min, frying or scrambling when the initial *Salmonella* inoculum is 10^8 per g or more (Humphrey *et al.*, 1989). The $D_{55°C}$ of *S. enteritidis* PT4 in egg is about 6 min, and Humphrey *et al.* (1989) found that this organism generally survived a heat treatment better than other egg-derived salmonellae. After 4 min immersion in boiling water, the yolk temperature of an egg initially at 7°C will only achieve 16°C, and although the centre temperature will continue to rise for some time after removal of the egg from the boiling water, it will still only just reach 56°C as a maximum, and around 10% of *S. enteritidis* will survive (Agriculture Committee, 1989; Humphrey *et al.*, 1989).

What then are the obligations and responsibilities of those in the large numbers of hotels, restaurants, cafés, etc. using shell eggs arising from the legal requirements for food businesses to

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ensure that 'adequate safety procedures are identified, implemented, maintained and reviewed' (Anonymous, 1995d) on the basis of HACCP principles? Should they remove lightly cooked egg dishes (many of which are traditional British dishes) from their menus; should they offer only 20-min boiled eggs, eggs fried both sides to dark brown or scrambled eggs cooked to the consistency of aquarium gravel, or should they include a health warning on the menus? Section 10 of Code of Practice 1: Responsibility for Enforcement of the Food Safety Act 1990 (Anonymous, 1991) states that 'District councils should investigate and take legal proceedings in *all* cases of contamination by microorganisms or their toxins, such as salmonella, listeria or botulism' (my italics). It seems to me that a hotelier, restaurateur or café owner attempting to follow carefully the UK government's guidance to caterers (Department of Health, 1993) or the IFST's Guidelines (IFST, 1992) is doing all that can reasonably be done. However, these guides make no reference to boiled eggs, fried eggs or the like – nobody can think of a way that a *caterer* can ensure that such dishes are free of *Salmonella.* Yet the Code of Practice is quite clear – if an environmental health officer were to take a fried egg, have it analysed and demonstrate the presence of *Salmonella enteritidis* PT4, then the Council *should* prosecute (even if the caterer has a 'due diligence' defence that they were scrupulously following either of the guides mentioned). There are obvious problems here in the reasonable interpretation of the legal requirement for a food business to undertake and implement a HACCP approach.

Firstly, the EC directive on eggs (EC, 1990, 1991) should be modified to *require* shell eggs to be refrigerated from the time of laying to the time of sale, with strict and short 'sell-by' limits, rather than prohibiting refrigeration of Class A eggs as at present. (Class A eggs are currently only *permitted* to be refrigerated at less than 5°C for not more than 24 h during transport or on retail premises for stock required for not more than 3 days' retail sale.) Secondly, should implementation of HACCP on the farm include a more serious adoption of measures to limit proliferation and spread of salmonellae in all poultry flocks (broiler, laying and breeding flocks)? There is evidence that the incidence of *Salmonella* infection of poultry can be considerably lessened by use of probiotics for competitive exclusion (CE) (in combination with strict attention to farm hygiene) (Stavric & D'Aoust, 1993) by the deliberate early introduction of adult microflorae (Pivnick & Nurmi, 1982; Fuller, 1992, 1997; Hofacre, 1997). Hirn and colleagues (1992) reported that the use of CE in Finland by > 70% of broiler growers resulted in < 5% of Finnish flocks being *Salmonella* positive, with the average number of salmonellae on contaminated carcasses being < 5 per carcass; they also reported that 70–80% of human salmonellosis in Finland was contracted outside the country, and only 15–20% of around 1200 cases of domestic origin were caused by contaminated poultry. There may be a case for requiring CE to be used throughout the poultry and egg industry. Mulder *et al.* (1997) concluded that CE against *Salmonella* infection of poultry is proven to be effective. They also observed that CE should be combined with a substantial reduction in the non-therapeutic use of antibiotics and improvements in farm hygiene and transportation (and, in the case of poultry for poultry meat production, further improvements in hygiene at the time of slaughter). The appearance of multiple drug-resistant salmonellae such as *Salmonella typhimurium* DT104 (Threlfall *et al.*, 1996a, 1996b) contraindicates the veterinary use of antibiotics in any countries, either as growth promoters or in prophylaxis to prevent the spread of salmonellae in farm animals. It is only a matter of time for *S. enteritidis* PT4 to display similar drug resistance, yet when it appears it will be treated by governments and the agricultural industry as an 'unexpected' development. This is surely a powerful argument in favour of prevention by probiotics combined with much tougher hygiene measures than are currently adopted (for example the banning of the use of untreated animal manures and slurries to fertilize grazing land). It is certainly an indication that governments should pay more attention to advice given by expert committees. The 'new' warnings about multiple drug-resistant pathogens requiring government attention are in no way new – the Swann Committee Report of 1969 (Report, 1969) warned of the outcome of the indiscriminate veterinary overuse of antibiotics for growth promo-

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tion and prophylaxis, yet the action taken in the UK only related to growth promotion and was only half-hearted at best. The problem is now having to be readdressed.

Whiting & Buchanan (1997) constructed a quantitative risk assessment (QRA) model for *S. enteritidis* in pasteurized liquid egg based on unit operations and stochastic simulation in an attempt to determine the relationship between the food processing operation and the public health impact. Their QRA indicated that pasteurization provides sufficient consumer protection from a high incidence of infected birds and from temperature abuse between the farm and the egg breakers but that temperature abuse during storage of the pasteurized egg would lead to a hazardous product.

HACCP should be taken even more seriously

The potential for cross-contamination by *Salmonella* from unpasteurized bulk raw egg to other sensitive foods (which will subsequently receive no or inadequate heat treatment) has been well documented for four decades (for example, see Newell, 1955). A food microbiologist could be forgiven for expecting that HACCP evaluations would by now ensure the prevention of major food poisoning outbreaks caused in this way. Yet a recent outbreak occurred in the US, in which there were 593 identified cases of *S. enteritidis* PT8 enteritis, *with an estimated total of 224 000 cases*, resulting from a nationally distributed pasteurized ice cream mix being transported in a bulk tanker that had previously been used to carry non-pasteurized bulk liquid egg without being subsequently disinfected (Hennessy *et al.*, 1996)!

Outbreaks of *Salmonella* enteritis have been caused by soft cheeses made from unpasteurized milk (see, for example, Maguire *et al.*, 1992), but occasionally even a hard cheese such as a Cheddar cheese may be involved (see, for example, CDSC, 1996a). More worrying is the possibility of verocytotoxigenic *Escherichia coli* (VTEC) occurring in such products, because the very low minimum infective dose (MID) and the acid resistance of the organism combine to ensure that foods acid enough to prevent multiplication of these *E. coli* may still act as a source of infection. Although the majority of VTEC outbreaks have been, and still are, associated with beef (burgers, minced beef, etc.) (see, for example, ACMSF, 1995; CDC, 1997a; Report, 1997), other animal-derived foods such as milk (Upton & Coia, 1994; CDSC, 1996b; Clark *et al.*, 1997), yoghurt (Morgan *et al.*, 1993) soft cheeses (Deschênes *et al.*, 1996; CDSC, 1997) and hard cheese (CDSC, 1998a) have been implicated. Sometimes pasteurized milk may be involved – in the outbreak described by Clark and colleagues (1997) there was a faulty pasteurizer with a damaged flow regulator valve; the authors noted an incomplete implementation of HACCP and an incomplete documentation of HACCP monitoring. It is unfortunate that full HACCP documentation is not at present required by UK legislation (Anonymous, 1995d). The Pennington Group (Report, 1997) recommended that all food businesses should apply *all* HACCP principles – and this includes the establishment of documentation concerning all procedures and keeping records of monitoring activities. Such documentation and records are vital for accurate traceability and verification and are invaluable in any epidemiological investigations. The guidance issued to UK local authorities by the Local Authorities Coordinating Body on Food and Trading Standards (LACOTS) indicates that although HACCP documentation is not currently legally required in the UK, nevertheless 'maintaining appropriate documented records should be generally recommended' to proprietors of food businesses, and that relevant advice be offered by local authority officers (LACOTS, 1997). Obviously, for small food businesses in particular, the range of knowledge necessary for a competent HACCP evaluation makes the advisory role of these officers crucial (LACOTS, 1995, 1997). I am of the opinion that proper documentation, particularly of monitoring records, is vital if HACCP is to be successfully implemented and that government legislation should include, for medium and large food businesses, an appropriate requirement.

If dangerous pathogens with very low minimum infective doses (MIDs; e.g. VTEC) become even more prevalent in dairy cattle, it will be difficult to avoid the logical extension of the need to

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pasteurize not only milk intended for drinking but also milk used for manufacture of cheese, etc. and difficult to argue against the need for appropriate legislation.

Perceptions of risk from food poisoning and food-borne disease

The approaches to control and prevention of food poisoning and food-borne disease are determined also by our perceptions of their aetiology. Traditionally, infection-type food poisoning (such as *Salmonella* enteritis) has been considered to be different in two main ways from a disease such as typhoid fever or infectious hepatitis A that may be food-borne. Firstly, in infection-type food poisoning, the primary clinical syndrome is acute and involves the gastrointestinal tract, with symptoms showing within 36 h or so, the organisms remain restricted to the intestinal lumen in the majority of patients. Secondly, it was believed that in infection-type food poisoning, a relatively high MID (perhaps of the order of 10^5 organisms or more) would require that the causative organisms had been permitted to multiply in the food. In the case of the food-borne diseases, infections may be systemic (as with typhoid fever), or localized in organs other than the intestinal tract (as with hepatitis A), and the MID is very low.

For different reasons, traditionally regarded intoxination-type food poisoning (such as botulism and staphylococcal food poisoning), with an incubation period short enough to permit confirmation of causation, have been considered separately from other food-borne diseases caused by toxins of microbial origin, in which there is a much longer time to the appearance of any symptoms (such as Balkan endemic nephropathy perhaps caused by ochratoxin or hepatoma perhaps caused by aflatoxin). The use of the word 'perhaps' in the preceding sentence underscores the problem. Chronic effects (such as the kidney damage sustained in Balkan endemic nephropathy), or carcinogenic or teratogenic effects show themselves so long after the consumption of the toxin-containing food that a causative link can only be hypothesized from epidemiological studies that highlight geographical links between the disease and a particular food consumption pattern. In both acute and long-term disease, the toxins will normally form within the food as the result of microbial growth and metabolic activity. Even this is not invariable – for example aflatoxin in cattle feed can be found in cow's milk as aflatoxin M_1 within 12 hours of the cows consuming the feed (Frobish *et al.*, 1986). Aflatoxin M_1 has both hepatotoxic and carcinogenic properties; its toxicity to ducklings and rats is similar to or only slightly less than that of aflatoxin B_1, and its carcinogenicity is probably around one or two orders of magnitude less than that of the highly carcinogenic aflatoxin B_1 (van Egmond, 1989). The absence of scientifically conclusive evidence for a link between mycotoxins and human carcinomas, for example, should not be used to deny the wisdom of using a HACCP approach to tackle the probable hazard, so that, for example, peanut products are not made from mouldy peanuts, and mouldy plant material is not incorporated into feed for milch animals.

In recent years, this distinction between the classical food poisonings and other food-borne diseases has become blurred, particularly in relation to infective dose, non-enteric involvement or incubation period, so that a nearly continuous aetiological spectrum can be seen. For example, classical food-poisoning *Salmonella* enteritis has been caused by chocolate confectionery, in which multiplication could not take place, and where the minimum infective dose was found to be extremely low. In an outbreak of *S. napoli* food poisoning caused by chocolate, it was determined that between 1 and 10 cells per gram provided an infective dose (Greenwood & Hooper, 1983), and in an outbreak of *S. nima* enteritis also caused by chocolate infections resulted from cell concentrations of 1 per 40 g, or lower (Hockin *et al.*, 1989). The likely reason for this low infective dose is the short residence time in the stomach combined with protection of the organisms by the high fat content of the chocolate against the effects of the gastric hydrochloric acid.

A range of apparently unusual foods or food components have been involved over decades in outbreaks of *Salmonella* enteritis; imported desiccated coconut (Wilson & Mackenzie, 1955), and paprika and paprika-dusted potato snacks (Lehmacher, Bockemühl & Aleksic, 1995) are two examples. Imported frozen fresh coconut milk has caused an outbreak of cholera (Taylor *et al.*,

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1993), and raw or briefly cooked cabbage was one of the vehicles in an outbreak of cholera (Swerdlow *et al.*, 1992). In many cases (for example both of the coconut-caused outbreaks just mentioned), an adequate knowledge of the method and circumstances of production in the country of origin could have identified the potential hazard.

Extension of HACCP from farm to consumer

The examples given above illustrate the need for extreme care in the identification of hazards during a HACCP evaluation and the importance of extending the HACCP system back to the primary production unit (whether agricultural, horticultural or fishery). An interesting further example has been provided in recent years by the implication of unpasteurized apple juice in *Escherichia coli* 0157:H7 infections. In an outbreak reported by Besser and colleagues in 1993, 90% of the apples processed were 'drops', collected from the ground under the trees. They were not washed before processing, and the apple juice was not pasteurized. It was concluded that the source of contamination was likely to be cow manure spread beneath the trees. The very low minimum infective dose of *E. coli* 0157:H7 means that although the acidity of the apple juice (pH 3.7–3.9) may retard or even prevent multiplication, this would not of itself confer safety, given the ability of the organism to survive in acid conditions. At first sight, counter-current washing of the apples with residual chlorine in the wash-water would seem to be an appropriate measure. However, in a similar set of two outbreaks of *E. coli* 0157:H7 infection and one of *Cryptosporidium* infection (*Cryptosporidium* also being acid resistant and having a low infective dose) occurring in 1996 (CDC, 1996, 1997b), the apple juice responsible for at least two of the three outbreaks was prepared from apples that had been washed. Thus, washing may be included as a measure but should not be relied on. In all the outbreaks, the apple juice was unpasteurized – an obvious control measure is to require pasteurization of the juice. Extension of HACCP into the field would identify that there should be a Code of Good Agricultural or Horticultural Practice that incorporates a requirement that manuring of the crop plants should not take place within a specified time before harvest. To specify an appropriate time requires identification of the survival rates of the pathogens that can be transmitted in this way. An alternative, or even additional, approach could be to decontaminate manures and slurries before or during application to the land (Report, 1997).

Iceberg lettuce imported from Spain was responsible for outbreaks of *Shigella sonnei* infection in a number of European countries (Frost *et al.*, 1995; Kapperud *et al.*, 1995). It was thought possible that faecally contaminated water was used to irrigate the lettuce or to cool it after packing.

Prepared melon salad has been responsible in the US for outbreaks of *Salmonella poona* enteritis (CDC, 1991; Madden, 1992) and for *E. coli* 0157:H7 infection (Feng, 1995). It has been shown that the relatively high pH of the melon flesh (pH 5.9–6.7) permits rapid multiplication of *Salmonella* when the prepared melon is kept above refrigeration temperature (Golden, Rhodehamel & Kautter, 1993). As restaurateurs (except for those who grow their own fruit) are not able to influence the identification or control of the hazards at growing or harvest, any legislation requiring restaurateurs to apply HACCP and to take appropriate steps will require them to take control action in their restaurants. Careful washing of the whole melons before cutting may help a little, but because of the deeply fissured surface of most varieties of melon, even the use of chlorinated wash-water is unlikely to eliminate the surface contamination completely and will therefore constitute only a partial CCP. Consequently, the most effective action would be to apply refrigeration to the dessert trolley. There is little doubt that temperature control regulations (Anonymous, 1995e) should be extended to include *all* foods on display in restaurants. It is unreasonable to expect a restaurateur (or street vendor – see Moy *et al.*, 1997) to have the microbiological knowledge to undertake an effective HACCP evaluation, so the introduction of such requirements into legislation puts the environmental health officer or hygiene officer into an advisory role rather than an enforcement role. However, washing and refrigeration will not pro-

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tect the consumer against infections by organisms with very low minimum infective doses (such as *E. coli* 0157:H7). In an outbreak of *E. coli* 0157:H7 infection caused by alfalfa sprouts (CDC, 1997e), it was concluded that the seeds themselves had been contaminated and that an effective method of decontaminating seeds or sprouts had yet to be determined.

Infections by the coccidian protozoon *Cyclospora cayatanensis* (Chiodini, 1994) started to be reported in the late 1980s. In an investigation of *Cyclospora* infections caused by fresh raspberries imported into the US from Guatemala, the fruit had reportedly been washed in 10 of 14 outbreaks (CDC, 1997c, 1997d). Although *Cyclospora* oocysts are inactivated by pasteurization or by freezing, there seems to be no easy way to decontaminate *fresh* raspberries or other fresh fruit. Thus, the only effective control measures are likely to be those that prevent contamination of the fruit in the field. It is worth observing that at present it is not known whether *Cyclospora* has an animal host other than human beings, and its ability to survive on soil, plant surfaces or in foods is yet to be determined. Nevertheless effective control measures applying to manuring and to use of organic fertilizers could quickly be introduced to lessen the hazard from bacterial pathogens such as *Salmonella*, *Shigella* and *E. coli* 0157:H7. Beuchat (1996) includes in his review paper a useful model HACCP plan for fresh-cut produce that has been produced by the International Fresh-cut Produce Association.

Another example demonstrating the importance of examining what happens to food right up to the point of consumption is provided by cases of campylobacteriosis associated with bottled pasteurized milk in the UK. In the UK, doorstep delivery of bottled pasteurized milk is common, and family outbreaks and point source outbreaks of *Campylobacter* enteritis have been caused as a result of contamination of the milk by birds pecking through the bottle-top seals to drink some of the milk while the bottles are standing outside on the doorstep (Riordan, Humphrey & Fowles, 1993). As the result of a survey of 551 cases, it has been estimated (Palmer & McGuirk, 1995) that this scenario can explain around 17 % of all cases of campylobacteriosis reported during the April to June peak seen every year in the UK.

The growing significance of helminthic parasites

With the increasing world trade in 'ethnic' foods, the widening of the areas for sourcing foods and the growing use of air-freighting high value specialist foods, helminthic parasites can give rise to problems world-wide and in countries in which they are not indigenous. Such parasites are killed by an adequate heat treatment (Cox, Kreier & Wakelin, 1998). However, meat may be deliberately eaten raw (e.g. 'steak tartare'), as may fish (e.g. sashimi). Raw meat or fish may be marinated or dry-cured. They may be undercooked accidentally or even deliberately. For example, rare beef steaks may still contain live *Taenia saginata*, and in some countries the traditional dish of rare-cooked pork meat may contain live *Trichinella spiralis*. *Anisakis simplex* infection can be acquired from raw fish (sashimi) eaten in Japanese restaurants (Kliks, 1983) and even from pickled and marinaded herring, for the *Anisakis* larvae can survive many days in vinegar (Yoshimura, 1998). However, freezing (to −20°C for 3–5 days) is effective in destroying the larvae. Legislation in The Netherlands now requires fresh herring to be frozen to at least −20°C for at least 24 hours before being sold to the public (Yoshimura, 1998). Infections of *Diphyllobothrium latum* (the fish tapeworm) can be acquired from North American salmon (Ruttenber *et al.*, 1984), and *Gnathostoma* can be found in fermented fish from Thailand (Yoshimura, 1998). The parasites are likely to be present in wild, caught fish as well as farmed fish, so prevention of contamination of the fish is unlikely to be possible. However, use of freezing of the raw food (e.g. fish or meat) or even of the product (e.g prosciutto or Parma ham) is a precautionary measure that could and should be adopted. Public awareness programmes could shift the responsibility for this measure to the general public, but it would be better to adopt such precautionary measures before retail sale occurs.

Risks presented to specific groups of the population

Certain risks tend to be confined to particular subgroups of the population. The best-known of

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these now is probably the susceptibility of pregnant women and immunocompromised or immunodeficient people to contracting *Listeria monocytogenes* infections.

A second example is the role of honey as a possible cause of infant botulism. In the US, infant botulism is now the most common form of botulism reported, with more than 1200 cases reported during the years 1976–94 (Midura, 1996). In a review of infant botulism, Midura (1996) commented that no investigator to date has reported the existence of preformed botulinum toxin in any honey sample. Honey, as found in the hive, and as presented as a food product, does not support multiplication and toxigenesis by *Clostridium botulinum*. The consumption of honey has not been associated with outbreaks of botulism as a food intoxination. However, in infant botulism, the absence of the adult gut microflora in infants under about 1 year old makes them particularly susceptible to colonization of the gut by *C. botulinum*. Thus, for them, the presence of spores of *C. botulinum* in the honey is the important factor. The fact that this contamination occurs in (or before) the hive, combined with the difficulties of trying to decontaminate honey, given the high heat resistance of the spores, meant that this cause of infant botulism had to be tackled primarily by public education, by recommending that babies and young infants were not given honey. Midura (1996) observed that, whereas about 30% of the cases of infant botulism in California in the early years of the studies were honey-associated, in recent years less than 5% of cases in California were fed honey before the onset of the illness, a reduction attributed to the success of the State's educational programme.

Use of modern detection and identification methods in epidemiological studies

When searching for organisms in environmental samples during epidemiological investigations of outbreaks, only positive results can provide pointers. In the case of organisms with very low MIDs, in particular, the non-detection by normal enrichment procedures means very little. For *E. coli* 0157 and *Shigella*, for example, selective enrichment media are relatively ineffective. In such cases, immunomagnetic separation from pre-enrichment or enrichment media can prove very valuable (see, for example, Cudjoe *et al.*, 1993). Using this method Upton & Coia (1994) were able to detect *E. coli* 0157 in environmental samples from a dairy involved in an outbreak associated with pasteurized milk.

Identification of sources of outbreaks can be much helped by techniques that achieve a fine subdivision of species or serovars. For example, in a study of 344 cases of *E. coli* O157:H7 infection occurring in Minnesota, Bender and co-workers (1997) used pulsed-field gel electrophoresis (PFGE) to identify 143 different PFGE patterns. Although at first sight PFGE appears to provide too much subdivision, in fact the causes of four general outbreaks were identified as a result of this typing. PFGE has been used similarly to study a *Salmonella javiana* outbreak (Lee *et al.*, 1998). In the cholera outbreak already mentioned, involving fresh-frozen coconut milk, PFGE patterns of isolates from patients and from the coconut were found to be indistinguishable and not to resemble any other strains tested (Taylor *et al.*, 1993). The subtyping methods that can be used for verocytotoxigenic *E. coli* have been summarized by the Advisory Committee on the Microbiological Safety of Food (ACMSF, 1995); they concluded that PFGE did not seem to provide particularly good subtyping for this bacterium. However, more recently Willshaw and colleagues (1997) stated that PFGE provides good discrimination of *E. coli* 0157 during epidemiological investigations.

Unfortunately, thoroughness of surveillance and epidemiological investigations is being threatened by public sector austerity in many countries (Berkelman *et al.*, 1994; Käferstein *et al.*, 1997).

Risk analysis

Risk analysis is a technique that is being considered in relation to food-borne illness (e.g. see Mossel *et al.*, 1995). Essentially a quantitative technique, it has been applied in a number of areas of human activity and concern, including engineering (Royal Society, 1992), the financial sector (Ansell & Wharton, 1992) and toxicology (Royal Society, 1992). It is now being applied to toxicological aspects of chemicals in food

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(Tennant, 1998, for review see the paper by Howgate, pp. 99–125, this issue). For a risk analysis to be complete, it involves risk assessment, risk management and risk communication. At present most of the work on food poisoning and food-borne disease has concentrated on quantitative risk assessment (QRA) (Jaykus, 1996; Lammerding & Paoli, 1997), with the mathematical tools of predictive microbiology (e.g. see McMeekin *et al.*, 1993) being applied for risk assessment (Foegeding, 1997; Walls & Scott, 1997). Quantitative risk assessment consists of four steps: identified either as hazard identification, exposure assessment, dose–response assessment, and risk characterization (Lammerding & Paoli, 1997); or as hazard identification, hazard characterization, exposure characterization and risk characterization (see, for example, Hathaway & Cook, 1997). For QRA to be reliable and useful, all aspects need to be quantifiable. At present there is a paucity of quantitative data for food poisoning and food-borne disease microorganisms; to take just one example, the infective dose depends on the nature of the food consumed and on the individual susceptibility of the consumer to a much greater extent than is the case with toxic chemicals. At present, most studies have been carried out retrospectively, to attempt to validate QRA models that have been constructed. Nevertheless, QRA has potential (Hathaway & Cook, 1997), and eventually full risk analyses should be possible. Examples of QRA applied to microbial hazards are the QRA by Whiting & Buchanan (1997) already referred to and the QRA by Cassin and colleagues (1998) concerning the hazard presented by *Escherichia coli* O157:H7 in beefburgers.

Conclusion

Buchanan (1997) has suggested that HACCP cannot be expected to control unknown hazards such as emerging food-borne pathogens and that 'controlling a new food-borne microbial threat requires moving the hazard as quickly as possible from being unknown to being known'. A good illustration of the need for the adoption of this philosophy is provided by the probable involvement of the bovine spongiform encephalopathy prion in new-variant Creutzfeldt–Jakob disease (see the paper by Blanchfield, pp. 81–97, this issue).

Nevertheless, a proper application of HACCP could avoid the emergence of many potential food-borne pathogens, as long as these display similar ecological and physiological characteristics similar to others that are known. For example, the appearance of outbreaks of infections by VTEC, *Salmonella* and *Cryptosporidium* caused by vegetables and fruit from land fertilized by human sewage or animal manures could readily have been foreseen and avoided by requiring the prior decontamination of sewage or slurries before use. Such a measure would also have the advantage of substantially reducing the cross-infection of farm animals grazing on such land.

It is not economically feasible (or statistically logical) to analyse *all* foods for *all* pathogens, toxigenic organisms and toxins. The increased international trade in foods (products as well as primary food materials) and the frequent involvement of imported foods in outbreaks underlines the importance of finding a way to implement an internationally standardized HACCP scheme that can be validated and verified remotely in the importing country. It is in this context that there is value in considering operating HACCP within a quality management system certificated to ISO 9001/9002. The need for verification of the efficacy of CCPs and for traceability in the event of an incident of food poisoning or food-borne disease requires the maintenance and retention of HACCP records and other quality management documentation.

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