The role of seafood in foodborne diseases in the United States of America

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Summary
In the United States of America, seafood ranked third on the list of products which caused foodborne disease between 1983 and 1992. Outbreaks connected with fish vectors were caused by scombroid, ciguatoxin, bacteria and unknown agents; in shellfish, unknown agents, paralytic shellfish poisoning, *Vibrio* spp. and other bacteria, followed by hepatitis A virus, were responsible for the outbreaks. At least ten genera of bacterial pathogens have been implicated in seafood-borne diseases. Over the past twenty-five years, bacterial pathogens associated with faecal contamination have represented only 4% of the shellfish-associated outbreaks, while naturally-occurring bacteria accounted for 20% of shellfish-related illnesses and 99% of the deaths. Most of these indigenous bacteria fall into the family Vibrionaceae which includes the genera *Vibrio*, *Aeromonas* and *Plesiomonas*. In general, *Vibrio* spp. are not associated with faecal contamination and therefore faecal indicators do not correlate with the presence of *Vibrio*. Viruses are the most significant cause of shellfish-associated disease: in New York State, for example, 33% and 62% of 196 outbreaks between 1981 and 1992 were caused by Norwalk virus and gastrointestinal viruses (small round structured viruses), respectively. In addition, several illnesses are a result of toxic algal blooms, the growth of naturally occurring bacteria and diatoms causing neurotoxic shellfish poisoning, paralytic shellfish poisoning, diarrhoetic shellfish poisoning, amnesic shellfish poisoning and ciguatera. Current estimates place the annual number of ciguatera cases at 20,000 worldwide.

Scombroid poisoning is the most significant cause of illness associated with seafood. Scombrotoxin is of bacterial origin and halophilic *Vibrio* spp. causing high histamine levels are implicated as the source. Scombroid poisoning is geographically diverse and many species have been implicated, namely: tuna, mahi-mahi, bluefish, sardines, mackerel, amberjack and abalone. Temperature abuse has been cited as a major cause of scombroid poisoning.

For routine work, the use of faecal indicators to predict the relative level of faecal contamination should not be disposed of. However, the main source of seafood illness is due to species which are not predicted by these organisms. In order to protect public health, routine surveillance using new pathogen-specific techniques such as polymerase chain reaction should be used. This, in combination with risk assessment methods and hazard analysis and critical control points, will begin to address the need for improvement in the safety of seafood.

Keywords
Introduction

Seafood contributes a significant proportion of the world food supply, and over 70 million tons are caught world-wide each year. Estimates report consumption averages of 13 kg per person per year for fish and shellfish (87). However, it is clear that seafood also remains an important source of foodborne disease.

Two books which give an extensive coverage of the topic of seafood safety were published in 1991 and 1994: these are 'Seafood safety' by the National Institute of Medicine (56) and 'Environmental indicators and shellfish safety' (47). From these books it is clear that contamination of seafood remains an important problem.

Data on foodborne disease outbreaks collected over a ten-year period (1983 to 1992) in the United States of America (USA) demonstrated that fish were the third most reported category according to vehicle of transmission: unknown vehicles ranked first and multiple vehicles ranked second (Fig. 1). Other countries have also reported the role of fish as a vehicle for foodborne disease: in Cuba, for example, fish and shellfish were associated with 12.8% of all foodborne disease outbreaks, a figure just slightly below pork and beef (each of which were associated with 15.4% of foodborne disease outbreaks) (112).

Fig. 1
Average outbreaks in the United States of America per year by vehicle of transmission, 1983-1992 (16, 24)

While the risk from consuming fish is largely associated with scombroid poisoning and post-harvest contamination, the risk posed by consumption of benthic invertebrates is linked to contamination of the source. Shellfish, particularly bivalve molluscs, are the most common seafood routes of human illness for viruses and Vibrio bacteria (56, 101, 109, 122). The disparity between the relative levels of bacterial contamination in fish and benthic invertebrates may best be explained by differences in the habitats and modes of feeding of the two groups. Fish (including bottom dwelling fish) tend not to be restricted to a small localised area and therefore are not restricted to a potentially contaminated area. Additionally, sediment and the sediment water interface (normal habitat for bivalve molluscs) are reservoirs for microbial pathogens. Bacterial concentrations here have been found at levels two to three times greater than those in the overlying water column.

Fig. 2

Fig. 3
Bacterial pathogens in seafood

At least ten genera of bacterial pathogens have been implicated in seafood-borne diseases. Pathogenic bacteria associated with seafood can be categorised into two general groups: enteric bacteria which are present due to faecal contamination (either in the environment or due to poor handling and processing) and bacteria which are normal components of the marine or estuarine environment. Over the past 25 years, bacterial pathogens associated with faecal contamination have accounted for only 4% of the shellfish-associated outbreaks in the USA (101). Naturally-occurring bacteria accounted for only 20% of shellfish-related illnesses but for 99% of the deaths (122) (Fig. 4). The remaining percentage of shellfish-related diseases is of unknown aetiology or is due to viral agents (Table I).

Pathogenic bacteria associated with faecal contamination

Important bacteria associated with faecal contamination of seafood include Salmonella, Shigella, Campylobacter, Yersinia, Listeria, Clostridium, Staphylococcus and Escherichia coli (36, 56). Few of these bacteria continue to pose a large-scale health threat through seafood consumption. The development of guidelines to minimise faecal contamination of shellfish and harvesting waters has greatly reduced the incidence of enteric bacteria in seafood (101). However, in some parts of the world these bacteria are still isolated from various seafoods, indicating the potential for transmission to humans (Table II).

Salmonella species

Until the mid-1950s, Salmonella Typhi was the most common bacterium associated with shellfish- vector disease (56, 101). Due to more effective surveillance and improved water quality, the incidence of S. Typhi in shellfish harvested in the USA has declined. The last shellfish-related typhoid fever outbreak occurred in 1954 (USA) (56, 101). The risk of S. Typhi infection from shellfish is still quite low in the USA: however, infections continue to occur in other parts of the world (56). In the United Kingdom (UK), S. Typhi was detected in more than 1.6% of shellfish sampled from open harvesting waters (121).

Non-typhoidal Salmonellae have been associated with both fish and shellfish in recent years. Salmonella spp., including S. Paratyphi and S. Enteritidis, have been detected throughout the world in shrimp and bivalves (8, 31, 62, 65, 76, 121). Between 1984 and 1993, the United States Food and Drug Administration (FDA) received reports of eight shellfish-
Table I
Selected outbreaks of bacterial disease associated with the consumption of seafood since 1986

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Year</th>
<th>Seafood</th>
<th>Cases</th>
<th>Location</th>
<th>Note</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shigella</td>
<td>1994</td>
<td>Shellfish</td>
<td>200</td>
<td>Mexico</td>
<td></td>
<td>94</td>
</tr>
<tr>
<td>Vibrio vulniﬁcus</td>
<td>1994</td>
<td>Eel (suspect)</td>
<td>1</td>
<td>Denmark</td>
<td>First report of V. vulniﬁcus in Denmark</td>
<td>14</td>
</tr>
<tr>
<td>Vibrio holliﬁse</td>
<td>1993</td>
<td>Oyster, crab</td>
<td>2</td>
<td>USA</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Vibrio cholerae 0139</td>
<td>1993</td>
<td>Shrimp (suspect)</td>
<td>1</td>
<td>USA</td>
<td>Shrimp originated in India</td>
<td>22</td>
</tr>
<tr>
<td>Vibrio cholerae 01</td>
<td>1991</td>
<td>Crab</td>
<td>13</td>
<td>USA</td>
<td>Crab originated in Ecuador</td>
<td>20, 21</td>
</tr>
<tr>
<td>Vibrio cholerae non-01</td>
<td>1989</td>
<td>Fish or shellﬁsh</td>
<td>24</td>
<td>USA</td>
<td>Isolated in the Gulf of Mexico</td>
<td>71</td>
</tr>
<tr>
<td>Vibrio parahaemolyticus</td>
<td>1989</td>
<td>Fish or shellﬁsh</td>
<td>27</td>
<td>USA</td>
<td>Isolated in the Gulf of Mexico</td>
<td>71</td>
</tr>
<tr>
<td>Vibrio vulniﬁcus</td>
<td>1989</td>
<td>Fish or shellﬁsh</td>
<td>10</td>
<td>USA</td>
<td>Gulf of Mexico</td>
<td>71</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>1989-1992</td>
<td>Fish, shellﬁsh</td>
<td>74</td>
<td>Croatia</td>
<td>6.17 cases/year</td>
<td>99</td>
</tr>
<tr>
<td>Listeria spp.</td>
<td>1989-1992</td>
<td>Fish, shellﬁsh</td>
<td>18</td>
<td>Croatia</td>
<td>1.5 cases/year</td>
<td>99</td>
</tr>
</tbody>
</table>

related Salmonella infections (122). Salmonella infections due to seafood consumption are still low compared with salmonellosis associated with other foods.

Other sewage-related bacterial pathogens
Campylobacter jejuni was identified as an emerging infectious agent for diarrhoea in humans in 1977 (125). Campylobacter has a short survival time in marine waters and seafood-borne infections are not expected. However, the survival rate increases dramatically within shellﬁsh, suggesting a protective relationship (5, 121).

In the USA, Shigella was implicated in 111 shellﬁsh-related cases and four outbreaks from 1898 to 1990 (101). Shigella may be an important potential disease agent as it has a low infectious dose and long survival time in clams and oysters (56).

Yersinia enterocoliﬁca infections result in appendicitis-like symptoms, including fever and abdominal pain, accompanied by diarrhoea or vomiting (39). Most Yersinia infections are not associated with a seafood vector (101). However, strains of Y. enterocoliﬁca have been identiﬁed in ﬁsh and shellﬁsh in both wild and aquaculture settings (56, 89). Additionally, Yersinia is a psychrotrophic bacterium which can multiply at low temperatures. This may increase the potential for cold-stored or frozen seafood to become a vector for human illness.

Listeria monocytogenes infections target speciﬁc groups. Spontaneous abortion and stillbirth have been caused in pregnant women by this bacterium. In infants and immuno-compromised individuals, infection leads to septicaemia and meningitis (125). Listeria spp. are also psychrotrophic and can grow under prolonged chilled conditions. Like Yersinia, Listeria has been isolated from a variety of ﬁsh and is potentially problematic for ready-to-eat products (13, 56, 89). Seafood-borne Listeria infections are believed to be under-reported in the USA (56).

Clostridium botulinum toxin type E is common in marine organisms. Botulism cases arising from seafood consumption

Table II
Sewage-related bacterial pathogens isolated from seafood, 1980 to 1997

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Source of contamination</th>
<th>Seafood</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonella Typhi</td>
<td>Environmental</td>
<td>Cockles, mussels, scallops, oysters</td>
<td>Ireland</td>
<td>121</td>
</tr>
<tr>
<td>Salmonella Enteritidis</td>
<td>Environmental</td>
<td>Bivalves</td>
<td>Ireland</td>
<td>121, 31, 40, 62, 121</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>Environmental, market</td>
<td>Bivalves, shrimp</td>
<td>Ireland, Asia, Europe, South Africa, Indonesia, USA, Honduras, Bangladesh, Kuwait</td>
<td>31, 40, 62, 121</td>
</tr>
<tr>
<td>Campylobacter spp.</td>
<td>Environmental</td>
<td>Bivalves</td>
<td>South Africa, Australia</td>
<td>31, 62</td>
</tr>
<tr>
<td>Clostridium botulinum</td>
<td>Market</td>
<td>Whiteﬁsh</td>
<td>USA</td>
<td>15</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>Market</td>
<td>Shellﬁsh</td>
<td>Mexico</td>
<td>94</td>
</tr>
<tr>
<td>Listeria spp.</td>
<td>Market</td>
<td>Trout, salmon, shrimp</td>
<td>Sweden, Asia, South-East Asia, Europe, North, Central and South America</td>
<td>40, 73</td>
</tr>
</tbody>
</table>
have been associated primarily with home-processed smoked or fermented fish products (54, 56).

*Staphylococcus* is commonly isolated from seafood in the USA. However, most outbreaks have been attributed to handling by infected persons (56). Seafood has not been an important vector in the transmission of *Escherichia coli* in the USA (56). To date, the emergent *E. coli* O157:H7 biotype has not been associated with seafood-related illness (101). However, cattle infected with this toxigenic strain may add to contaminated run-off waters reaching shellfish beds.

**Naturally occurring bacterial pathogens: an emergent problem**

Since the last outbreak of shellfish-related typhoid fever in the USA in the 1950s, the nature of seafood illnesses has changed. Prior to this, faecal contamination was the main source of bacterial pathogens in seafood. Over the last few decades, however, naturally-occurring bacteria have become the leading cause of shellfish-borne illness of known aetiology (122). Most of these indigenous bacteria belong to the family Vibrionaceae which includes the genera *Vibrio*, *Aeromonas* and *Plesiomonas*.

Members of the Vibronaceae family are halophilic or halotolerant, in other words are characterised by their salt requirement. These are the dominant bacteria in warm marine and estuarine waters. All members of this group show an increase in abundance in warmer waters and an apparent reduction in numbers during cooler months. *Vibrio* spp. find reservoirs in the intestinal tract of fishes, within shellfish, in sediments and plankton (33, 37, 38, 83, 107). Most species give positive results when tested for chitinase activity and are often found colonising the exoskeletons of copepods and other zooplankton (35). In general, *Vibrio* spp. are not associated with faecal contamination and therefore faecal indicators do not correlate with the presence of *Vibrio* spp. (64).

Raw oyster consumption is the most common route for human infection with *Vibrio* spp. Ninety-five percent of cases in the USA are associated exclusively with the American oyster (*Crassostrea virginica*) (101). Gastroenteritis is the main disease associated with *Vibrio* spp.: however, systemic infections occur in high-risk groups and are responsible for a high mortality rate (72).

*Plesiomonas* and *Aeromonas* are common in estuarine waters and have been isolated in shellfish. Based on epidemiological investigations, *Plesiomonas shigelloides* has been a suspected cause of gastroenteritis for 40 years. Between 1978 and 1987 this bacterium was responsible for 0.5% of shellfish-related disease. While the pathogenicity of both *Aeromonas* and *Plesiomonas* has been questioned, Krovacek et al. found that marine and clinical isolates of *Aeromonas* had similar virulence characteristics (56, 66).

**Vibrio species**

Twelve pathogens are known within the *Vibrio* genus including *Vibrio cholerae*, *V. parahaemolyticus* and *V. vulnificus*. These three are the dominant and emerging pathogenic species within the Vibrionaceae.

**Vibrio cholerae**

*Vibrio cholerae* is not strictly a naturally-occurring bacterium. In the last seven cholera pandemics, the main route of infection has been through the consumption of faecally-contaminated water (124). However, *V. cholerae* is halotolerant and survives well in warm waters of moderate to low salinity (27, 84, 96). In addition, *V. cholerae* has several reservoirs in the aquatic environment, which are of concern with regard to human infections (19, 124).

The primary vector for seafood-borne illness is consumption of raw oysters. In several cases, cooked crab has also been implicated (20, 21, 118). *V. cholerae* is responsible for the third-highest number of shellfish-related illnesses, after non-cholera *Vibrio* spp. and Norwalk viruses (122). Toxigenic O1 (epidemic biotype) infections are associated with profuse, watery diarrhoea. Non-toxigenic, non-O1 biotype (except O139) infections result in septicaemia and mild gastroenteritis (56).

Toxigenic, epidemic-type strains of *V. cholerae* have not been problematic in most developed countries due to effective sanitation and monitoring practices. However, given environmental reservoirs within fish, shellfish and even plankton, there is potential for these toxigenic strains to colonise novel regions. The practice of ships exchanging ballast waters close to shores illustrates this point. In 1991 and 1992, toxigenic *V. cholerae* O1 (El Tor) were isolated from bilge and ballast water of cargo ships docked in the northern Gulf of Mexico (74). Since then, the O1 El Tor (Latin American) biotype has been isolated from oysters in the northern Gulf (84).

Like other naturally-occurring bacteria, *V. cholerae* is not well correlated with faecal indicators such as *E. coli*. Despite having a faecal association with *E. coli*, *V. cholerae* survives longer and in higher numbers in surface waters (127).

The introduction of *V. cholerae* into novel regions, the presence of reservoirs and the emergence of new toxigenic strains create the potential for pandemics to reach regions which were previously free of the bacterium.

**Non-cholera Vibrio species**

Non-cholera *Vibrio* spp. account for more cases of shellfish-related disease than any other known agent. Between 1984 and 1993, 406 cases were attributed to this group (122).

This group shares the same reservoirs as *Vibrio cholerae* (fish, shellfish and plankton). The two groups also share a similar
seasonality. Infections and detection of *Vibrio* spp. in the environment are more likely to occur during the warm months (72, 101). Non-cholera species, though, are more halophilic, and the consumption of seafood, rather than contaminated water, is the main source of infection (72).

**Vibrio parahaemolyticus**

In the USA, *Vibrio parahaemolyticus* was implicated in 159 cases and 14 outbreaks of shellfish-related disease between 1967 and 1990 (101). In Japan, most seafood-borne disease is related exclusively to this species (39). Infections result in gastroenteritis primarily through consumption of raw or undercooked shellfish (101).

*Vibrio parahaemolyticus* has been isolated from a variety of fish and shellfish throughout the world. The pathogen has been isolated from temperate, subtropical and tropical coastal regions (7, 49, 60, 78). While *Vibrio* spp. thrive in warm waters, *V. parahaemolyticus* has also been isolated from several sources in the Pacific Northwest (USA). In Washington State, *V. parahaemolyticus* was detected in all sediments sampled, in oysters, in clams and in more than ten types of fish (7). Seventy-seven percent of sampled oysters from tropical regions (Brazil) revealed the presence of the pathogen (78).

*Vibrio parahaemolyticus* is generally found at ambient temperatures above 15°C. However, post-harvest temperature abuse can result in multiplication of bacteria by 1-4 orders of magnitude (30). During the summer months especially, shellfish should be placed on ice immediately: no growth has been observed at temperatures below 10°C. At the other end of this temperature spectrum is the incidence of *V. parahaemolyticus* in frozen fish products (85). This species shows psychrotrophic properties, and the bacterium has been recovered at frequencies of up to 25% in frozen peeled shrimp (123). The bacteria are apparently protected within the tissues of some shellfish.

As expected, given the indigenous nature of this species, faecal indicators do not predict the presence of this pathogen. Additionally, *V. parahaemolyticus* may be part of the natural flora of shellfish as it is not removed by controlled purification procedures (depuration) (59).

**Vibrio vulnificus**

Unlike other Vibrionaceae, *Vibrio vulnificus* infections rarely result in gastroenteritis. While wound infections are common due to recreational exposure, most infections of *V. vulnificus* result in septicemia due to the consumption of raw oysters. Ninety-nine percent of all *V. vulnificus* infections are associated exclusively with the American oyster, *Crassostrea virginica* (122). *V. vulnificus* has also been detected in a variety of fish at higher concentrations than those found in oysters (33). However, rates of infection are low as fish are usually cooked thoroughly.

*Vibrio vulnificus* was responsible for 160 cases of shellfish-borne illness in the USA between 1967 and 1990, more than any other bacteria (101). The highest incidence of shellfish-related death (95%) is also due to this species (122). Additionally, *V. vulnificus* has a rapid onset and the highest mortality rate of any of the Vibrionaceae. In Florida (1981-1994), approximately 60% of people infected by eating raw oysters died (72). Similar fatality rates have been reported elsewhere (52, 53).

In general, healthy individuals are not affected by *Vibrio vulnificus*. Certain groups are at greater risk of infection and death as a result of the consumption of raw oysters. These include those with liver damage and the immuno-compromised (72, 91) (Fig. 5). In other individuals, iron in serum is bound to transferrin: as a result, there is insufficient free iron to assist growth of *V. vulnificus* in human blood. However, when the liver is damaged, there is often an overload of free (non-transferrin-bound) iron in serum. Given this excess iron, the bacteria can readily multiply (91).

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**Fig. 5**

*Vibrio vulnificus* infections and deaths associated with high-risk conditions in Florida, 1981-1994 (72)
While all of the Vibrio spp. show seasonality in the environment, in V. vulnificus the seasonality is more pronounced (63). Infection with pathogenic Vibrio spp., due to the consumption of oysters from Apalachicola Bay, Florida, occurred in every month of the year except April. Only V. vulnificus showed a marked seasonality, with a cluster of infections between July and October (63). Of cases reported in Florida between 1981 and 1994, 92% of V. vulnificus infections and 91% of deaths occurred between April and August (72).

The seasonality of Vibrio vulnificus infections can be explained in two ways. First, growth of this bacterium is strongly related to temperature. The optimal conditions are 13°C-22°C and salinity of 10 (61). Below 10°C, V. vulnificus ceases to multiply and begins to enter a 'viable but non-culturable' state (30, 92). This 'over-wintering' stage explains the apparent reduction of V. vulnificus in cooler months. Secondly, V. vulnificus cells may appear as one of two morphotypes: opaque and virulent; or translucent and less virulent. The opacity of the virulent morphotype is due to an acidic polysaccharide coating (102). This coat is an antiphagocytic surface antigen which allows the cells to resist bactericidal action (both in humans and in oysters) (50, 91). Additionally, free iron in serum is not required for growth of this morphotype. The cells seem able to use transferrin-bound iron (91). These more virulent cells are more prevalent in warmer months (122).

Vibrio vulnificus occurs throughout the world, primarily in warm waters of moderate salinity. In Brazil, 12% of the oysters found in retail markets gave positive results for V. vulnificus (78). In Chesapeake Bay, V. vulnificus accounted for 0.6% to 17.4% of the total bacterial population in warm months. Throughout May and June, all plankton samples gave positive results for the opaque morphotype (126). Even as far north as Canada (Prince Edward Island), New Hampshire and Maine, V. vulnificus has been isolated from water, fish and shellfish (49, 93). V. vulnificus has been isolated less frequently in Europe. The first case of V. vulnificus infection in Sweden was reported in 1994 (80). In the Netherlands, V. vulnificus was isolated in three of 11 water samples taken during summer. Positive results were only found when the water temperature reached 20°C (114). The coastal regions of the Gulf of Mexico are the primary source of shellfish implicated in V. vulnificus infections (53). For those cases in which the source of the shellfish could be traced, 23% were from the Gulf Coast (122). Only five States of the USA (Alabama, Florida, Louisiana, Texas and Mississippi) currently report V. vulnificus infections to the Centers for Disease Control: these States border the Gulf of Mexico (26).

Vibrio vulnificus is a naturally-occurring bacterium and a commensal organism within oysters (49). Therefore, the presence of V. vulnificus in waters or shellfish is not predictable through the presence of indicator organisms (63). Additionally, V. vulnificus is selectively retained in oyster tissues during controlled purification procedures (depuration) (44, 59). Most of the time there was no significant change between V. vulnificus levels in pre- and post-depurated oysters: however, in one case the concentration actually increased by three orders of magnitude (59). This suggests that V. vulnificus may colonize and multiply within tissues of oysters.

Vibrio vulnificus may multiply quickly after harvesting if proper temperature conditions are not maintained. If oysters are immediately placed at 10°C or less, no multiplication of the bacteria occurs in the shellfish. Yet, if the oysters are stored for one day at 22°C to 30°C, the level of V. vulnificus increases by one to two orders of magnitude (30). Substantial multiplication may take place during post-harvest transport. Currently, no specific storage regulations for transport exist in the USA, and summer temperatures are warm enough to promote appreciable multiplication (30). Freezing and vacuum-packaging does decrease the levels of V. vulnificus in oysters with time. However, even after 30 days at –20°C, two log units of the bacteria were still detectable (95).

Vibrio vulnificus presents a special problem of public health significance. While infection may be rapidly fatal for a few high-risk groups, the majority of consumers will experience no adverse effects. Given the ubiquitous nature of this bacterium in warm estuarine waters, the potential for outbreaks always exists. Over the last 16 years, the incidence of V. vulnificus infections has increased substantially (Fig. 6). Consumer education and better detection are the most realistic options to protect public health.

Enteric viruses are obligate human pathogens. These agents are small (only nanometers in size) and have a simple structure of a protein coat surrounding a core of genetic material (ribonucleic acid [RNA] or deoxyribonucleic acid...
Viruses. RNA:

Table III

<table>
<thead>
<tr>
<th>Viruses</th>
<th>Size (nm)</th>
<th>Nucleic acid</th>
<th>Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enteroviruses: poliovirus, coxsackievirus A and B, echovirus</td>
<td>20-30</td>
<td>RNA</td>
<td>Paralysis, aseptic meningitis, herpangia, respiratory illness, pleurodynia, pericarditis, myocarditis, congenital heart anomalies, nephritis, diarrhoea, fever, rash</td>
</tr>
<tr>
<td>hepatitis A virus (HAV), epidemic non-A, non-B (hepatitis E virus)</td>
<td>27</td>
<td>RNA</td>
<td>Infectious hepatitis</td>
</tr>
<tr>
<td>Adenovirus</td>
<td>68-85</td>
<td>DNA</td>
<td>Acute conjunctivitis, diarrhoea, respiratory illness, eye infection, infantile gastroenteritis</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>27</td>
<td>RNA (double stranded)</td>
<td>Gastroenteritis</td>
</tr>
<tr>
<td>Norwalk virus, calicivirus, astrovirus, Snow Mountain agent, small round structured virus (SRSV), (known collectively as small round viruses, SRVs)</td>
<td>27</td>
<td>RNA</td>
<td></td>
</tr>
</tbody>
</table>

Table IV summarises some noteworthy outbreaks.

Perhaps the most comprehensive data on surveillance of virus-associated disease comes from New York State (119). Twelve years of data collection have shown that of 98 outbreaks, 11 were caused by HAV, 57 were due to other gastrointestinal viruses and 26 were of unknown cause (Fig. 8) (3).

Hepatitis viruses

Both hepatitis A and non-A, and non-B hepatitis have been linked epidemiologically to shellfish-associated illness (32, 57). In studies conducted in the USA and the UK, an estimated 19% to 25% of hepatitis cases may be due to contaminated shellfish (17, 32, 57). Studies in Germany found that 20% of cases of infectious hepatitis were associated with shellfish (110). Therefore, shellfish may be an important source of sporadic cases and may be responsible for the endemic levels of hepatitis.

Enteroviruses

The enteroviruses in polluted waters have been studied since the 1940s, and methods for the recovery and detection in water, sediment and shellfish, and the survival ability have been evaluated extensively (57, 105). These viruses have been commonly isolated from marine waters and shellfish (82). In surveys performed in the USA, between 28% and 63% of the samples of shellfish gave positive results for enteroviruses in areas closed to harvesting (0.2 to 224 plaque forming units [PFU]/100 g). In areas open to harvesting, these were recovered from 9% to 40% of the samples and levels ranged from 0.3 to 200 PFU/100 g and 2.9 to 46 PFU/100 l of water (105). Waters are often closed to harvesting due to influences of rainfall, tidal flushing, sewage treatment plant discharges and septic tanks. Bioconcentration and accumulation in shellfish may increase the concentration of viruses by 10 to 100 fold compared to the water column or sediment (57).
Table IV
Noteworthy virus outbreaks associated with shellfish

<table>
<thead>
<tr>
<th>Virus</th>
<th>Year</th>
<th>Shellfish</th>
<th>Cases</th>
<th>Location</th>
<th>Note</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAV</td>
<td>1955</td>
<td>Clams</td>
<td></td>
<td>Sweden</td>
<td>First documented outbreak</td>
<td>103</td>
</tr>
<tr>
<td>HAV</td>
<td>1961</td>
<td>Oysters</td>
<td>84</td>
<td>Mississippi/Alabama, USA</td>
<td>Sewage pollution, with 40% developing non-specific gastroenteritis 15-24 hours post exposure</td>
<td>76</td>
</tr>
<tr>
<td>HAV</td>
<td>1973</td>
<td>Oysters</td>
<td>263</td>
<td>Louisiana, USA</td>
<td>Harvested from approved oyster-growing areas</td>
<td>97</td>
</tr>
<tr>
<td>HAV</td>
<td>1978</td>
<td>Mussels (boiled and steamed)</td>
<td>41</td>
<td>England</td>
<td>Boiled and steamed after going to a cleansing station</td>
<td>9</td>
</tr>
<tr>
<td>HAV</td>
<td>1984</td>
<td>Mussels/clams</td>
<td>75</td>
<td>Livorno, Italy</td>
<td>Identified as annual incidence rate doubled</td>
<td>79</td>
</tr>
<tr>
<td>HAV</td>
<td>1996</td>
<td>Many shellfish</td>
<td>271</td>
<td>Puglia, Italy</td>
<td>Risk factor associated with shellfish stored in water</td>
<td>75</td>
</tr>
<tr>
<td>HAV</td>
<td>1998</td>
<td>Clams</td>
<td>300,000</td>
<td>Shanghai, China</td>
<td>Largest outbreak documented</td>
<td>48</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>1978</td>
<td>Oysters</td>
<td>2,000</td>
<td>Sydney, Australia</td>
<td>First Norwalk outbreak</td>
<td>96</td>
</tr>
<tr>
<td>Snow Mountain agent</td>
<td>1977</td>
<td>Clams</td>
<td>83</td>
<td>Massachusetts, USA</td>
<td>First outbreak, clams were baked</td>
<td>113</td>
</tr>
<tr>
<td>Small round viruses:</td>
<td>1985 to 1986</td>
<td>Oysters, cockles, mussels</td>
<td>NR</td>
<td>United Kingdom</td>
<td>Six outbreaks demonstrating the importance of shellfish-associated viral gastroenteritis and newly recognised viruses</td>
<td>3</td>
</tr>
<tr>
<td>SRSV</td>
<td>1993</td>
<td>Oysters</td>
<td>180</td>
<td>Louisiana, USA</td>
<td>Raw or steamed oysters affected, 14 States received the product</td>
<td>23</td>
</tr>
</tbody>
</table>

HAV: hepatitis A virus

NR: not reported

SRSV: small round structured virus

Enteroviruses may remain infectious for nine days in marine waters and nineteen days in sediment, and up to one month in shellfish (98).

In addition to shellfish, shrimp and other benthic invertebrates may be an unrecognised risk associated with seafood-borne disease. Botero et al. (10) reported that 40% of all shrimp harvested from contaminated waters in Venezuela yielded enteroviruses.

These viruses cause a wide range of diseases in different individuals (from aseptic meningitis which may be very mild, to chronic diseases such as myocarditis) and may not be easily related to a common source outbreak. Outbreaks associated with shellfish have not been readily documented. Based on the data obtained by monitoring and survival studies, exposure to enteroviruses clearly does occur through the ingestion of contaminated shellfish. The public health impact is probably not fully appreciated.
Histamine and environmental Important seafood rare in USA

Small round viruses

Small round viruses (SRVs) were first identified with the use of the electron microscope: the group includes Norwalk virus, Snow Mountain agent, astroviruses, caficiviruses and other of the electron microscope: the group includes Norwalk virus, Snow Mountain agent, astroviruses, caficiviruses and other. There are extensive data showing these viruses to be a major cause of shellfish-associated disease: SRVs are possibly the significant group of viruses causing adult gastroenteritis (32, 57). Symptoms include vomiting, diarrhoea, fever and in some cases respiratory illness (16). The viruses are heat-stable and are more resistant to chlorine than the bacteria which are used to disinfect waste water.

Rotavirus and adenovirus

These viruses have not been documented as causing shellfish-associated disease. This may be due to low survival in the marine environment or poor diagnostics. Rotaviruses and adenoviruses types 40 and 41 are often associated with infant diarrhoea but may not be considered in adults. In addition, adults may excrete only low quantities of the virus which could be missed under the electron microscope.

Toxins in shellfish and fish

Several illnesses are associated with the consumption of shellfish and fish as a result of toxic algal blooms, naturally-occurring bacteria and diatoms (Table V) (56). Diseases include neurotoxic shellfish poisoning, paralytic shellfish poisoning, diarrhoetic shellfish poisoning, amnesic shellfish poisoning and ciguatera. Puffer fish poisoning and scombroid poisoning have been associated with toxins derived from naturally-occurring marine bacteria (56, 130). Many of these intoxications result in minor symptoms and the number of cases world-wide is probably under-reported. Scientists believe that the frequency of harmful algal blooms is increasing world-wide. This increase may reflect coastal

### Table V

**Natural toxins associated with seafood** (56)

<table>
<thead>
<tr>
<th>Source of poison or toxin</th>
<th>Type of poison or toxin*</th>
<th>Extent of problem in the USA and worldwide</th>
<th>Location</th>
<th>Seafood involved</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paralytic shellfish poisoning (DSP)</strong></td>
<td>Neurotoxin, purine base, very water soluble</td>
<td>Important seafood in Japan; 100 cases, 50 deaths per year; rare in USA</td>
<td>Areas of Pacific around China and Japan, rare in USA</td>
<td>Mussels, clams, some fish; poison in digestive gland, siphon</td>
</tr>
<tr>
<td><strong>Puffer fish poisoning (PFP)</strong></td>
<td>Neurotoxin, slightly water soluble</td>
<td>Largest seafood problem, 50,000 cases per year; 0.1% mortality</td>
<td>Tropical areas around world; in USA, mainly around Florida</td>
<td>Puffer or globefish (tetradon), poison in liver, gonads and roe</td>
</tr>
<tr>
<td><strong>Bacterial action</strong></td>
<td>Lipid-soluble, polyether multicompontent</td>
<td>High mortality rate, potentially world-wide problem, none in USA</td>
<td>Heaviest around Japan and Europe, no case in USA</td>
<td>Musseis, clams, scallop, toxin in digestive gland</td>
</tr>
<tr>
<td><strong>Diatom</strong></td>
<td>Substrate okadaic acid, lipid-soluble polyether multicompontent</td>
<td>Massive fish kills, environmental problems</td>
<td>Mostly west coast of Florida, Caribbean</td>
<td>Bivalves and most plankon feeders</td>
</tr>
<tr>
<td><strong>Diatom</strong></td>
<td>Histamine and histamine-like substances</td>
<td>World-wide</td>
<td>Western USA</td>
<td>Mussels and clams</td>
</tr>
<tr>
<td><strong>Bacterial</strong></td>
<td>Neurotoxin and cytotoxin, domoic acid</td>
<td>Eastern Canada; north-east USA</td>
<td>Eastern Canada; north-east USA</td>
<td>Mahi-mahi, tuna, bluefish, mackerel, skipjack</td>
</tr>
</tbody>
</table>

*All toxins appear to be heat-stable
nutrification and dispersal of toxic species over shipping routes and with ocean currents (108).

**Neurotoxic shellfish poisoning**

Neurotoxic shellfish poisoning (NSP) causes symptoms of numbness, gastrointestinal effects, dizziness and muscular aches in humans. NSP is caused by a concentration of the red tide dinoflagellate *Gymnodinium breve*, and its neurotoxin (brevetoxin) in shellfish. *G. breve* occurs primarily in the Gulf of Mexico, and most cases of disease are associated with Gulf shellfish. However, these planktonic algae have been documented as far north as Cape Hatteras off North Carolina in the Atlantic Ocean (108). The Gulf Stream current system effectively transported *G. breve* to this new location (56).

Between 1973 and 1988, 53 cases of NSP were reported in the USA. However, symptoms are often mild and may go unreported. The closure of shellfish harvesting beds during red tide events effectively curtails the disease in humans but this action has economic impacts (56).

**Diarrhoetic shellfish poisoning**

Diarrhoetic shellfish poisoning (DSP) causes gastrointestinal distress and abdominal cramping (56). DSP is the result of okadaic acid production by dinoflagellates concentrated in mussel, oyster and scallop tissues (39). Algae most often implicated in disease outbreaks are *Dinophysis* spp., including *D. fortii* and *D. acuminata*. *Prorocentrum* spp. is another potential DSP dinoflagellate. DSP has been a problem primarily in Japan, and occasionally in Europe. No cases of DSP have been reported in the USA, although *Dinophysis* has been recovered from USA waters (56).

**Amnesic shellfish poisoning**

Amnesic shellfish poisoning (ASP) results in gastroenteritis and neurological symptoms, particularly memory loss (111). Symptoms often occur in the elderly and resemble Alzheimer’s disease (39). ASP was the first known intoxication due to a diatom. In 1987, *Nitzschia pungens* was identified as a producer of domoic acid, which was responsible for the first outbreak of ASP (Canada, 107 cases) (56). Domoic acid-producing *Pseudo-nitzschia* spp. have been isolated world-wide (111).

**Paralytic shellfish poisoning**

Paralytic shellfish poisoning (PSP) is a serious illness which leads to neurological symptoms, paralysis and sometimes death. Toxigenic dinoflagellates, producing 20 derivatives of saxitoxin, accumulate within shellfish (especially mussels, cockles, clams and scallops) (39). Saxitoxins are considered the most potent of the algal toxins (56). *Alexandrium* (formerly *Gonyaulax*) tamarense and *A. catenella* have both been implicated in PSP in the USA (56). The cyanobacterium *Anabaena circinalis*, which has been isolated from freshwater mussels, can produce two types of saxitoxin; C-toxins and gonyautoxin (90). This represents another potential vehicle for illness. Generally, PSP is heat-stable, and outbreaks have occurred from consumption of cooked shellfish (18). Yet in lobster, more water-soluble toxins showed some decrease with cooking (57). In the USA, 282 cases of PSP were reported between 1978 and 1986 (56). Outbreaks have been documented primarily in cool waters, for example in Alaska, California, Maine, Massachusetts, Oregon and Washington (18, 56). The closure of shellfishing areas during blooms has helped to reduce exposure to PSP toxins.

**Ciguatera**

Ciguatera is a clinical syndrome which causes several gastrointestinal and neurological disorders. Ciguatera usually results from the consumption of tropical reef fish or higher carnivores from tropical or subtropical regions (56). Several benthic dinoflagellates are associated with a range of ciguatoxins. The epiphytic *Gambierdiscus* toxica may be the main source of the toxins. Other dinoflagellates implicated in ciguatera include *Amphidinium cartieri*, *A. klebsi*, *Coolia monotis*, *Ostreopsis ovata*, *O. siamensis*, *Prorocentrum concavum*, *P. lima* and *P. rhathymum* (128). The principal toxins produced are ciguatoxin, scaritoxin, maizotxin and palytoxin (43, 56, 129). Ciguatera-related toxins are bioaccumulated. Herbivorous fishes which feed on toxic benthic algae are consumed by higher carnivores. The level of toxins in fish tissues increases further up the food chain. An example of this is a 500-case outbreak of ciguatera in Madagascar due to the consumption of shark meat. Twelve percent of those affected died. As a top carnivore, the shark probably carried very high levels of ciguatoxins (46).

Current estimates place the world-wide annual number of ciguatera cases at 20,000 (129). Between 1978 and 1987, 791 cases were reported in the USA (56). It is believed that disturbances to reefs, for example during hurricanes and human recreational use, will open a niche for more toxic algae. This may subsequently cause an increase in ciguatera poisonings.

**Puffer fish poisoning**

Puffer fish poisoning (PFF) results in similar symptoms to those of PSP. Illness results from the consumption of fish from the Tetraodontidae family, including puffer fish. Unlike the toxins discussed thus far, the source is not considered to be diatoms or dinoflagellates. The microbial flora of the fishes are responsible for production of tetrodotoxin (39). Bacteria implicated thus far include *Vibrio* spp., *Listonella pelagia*, *Alteromonas* spp. and *Shewanella* spp. (130). Cases are most prevalent in Japan, where an estimated 200 people per year are affected by PFF. The mortality rate approaches 50% (39). Outbreaks are rare in the USA; three cases were reported in 1996 but the source was puffer fish imported from Japan (25).

**Scombroid poisoning**

Symptoms of scombroid poisoning are gastrointestinal and neurological in nature. The scombroid toxin produced is
believed to be of bacterial origin: the most commonly implicated group are halophilic *Vibrio* spp. (56). The nature of the poisoning is caused by the ingestion of fish with high histamine levels (39). Scombroid poisoning occurs in geographically diverse regions, and several types of fish have been implicated. These include tuna, mahi-mahi, bluefish, sardines, mackerel, amberjack and abalone (39).

Temperature abuse has been cited as a major cause of scombroid poisoning (39, 56). Multiplication of fish-associated *Vibrio* spp. and histamine production are maximised at or near 30°C (56). Cooking has no impact on the toxic effect (39).

Like ciguatera, this illness is more prevalent than the toxic shellfish-associated illnesses. Between 1978 and 1987, 757 cases of scombroid poisoning were reported in the USA (56). Under-reporting of this illness is a world-wide problem (39).

Monitoring data and risk assessment for use with hazard analysis and critical control points

The seafood hazard analysis and critical control points (HACCP) concept is focused on the identification of sources and points of contamination, levels, transmission, fate and transport of micro-organisms including regrowth and inactivation potential, and finally on the possibility of exposure of the consumer to the contaminant. Once these pathways have been identified, the most effective control strategies can be implemented and the best means for monitoring the control points can be established. For shellfish- and viral-associated diseases, the data suggest that harvesting from unapproved sources is associated with more than 30% of the outbreaks. The current tagging system appears to be inadequate. Even reliance on depuration or relaying (the moving of shellfish from contaminated harvesting waters to pristine waters for a period of time, usually one to two weeks) may not provide the protection needed.

The purpose of HACCP is to identify and monitor points where there is the greatest risk of contamination. Methods are needed for this and risk assessment methods are needed to determine the outcome associated with failure of the control points and the benefits achieved in regard to protection of public health.

Methods

Better characterisation of the quality of harvesting waters and shellfish is clearly needed. The bacteriological indicator system is severely limited, thus the development and use of new methods for direct detection of the viruses, naturally-occurring *Vibrio* spp. and the seafood toxin-associated micro-organisms in waters, sediments and shellfish will become necessary. Although methods for the biotoxins are available, the reliance on animal tests will deter most laboratories from widespread monitoring.

Bacteria

Some basic problems exist for preventing bacterial infections resulting from consumption of contaminated seafood. The faecal indicator system for shellfish-harvesting waters has been very effective in protecting consumers against general types of faecal contamination. However, several pathogenic bacteria are not predicted by this system. This is expected for naturally-occurring bacteria, but appears also to be true for some faecal-related bacteria (*Salmonella* and *Campylobacter*) (31, 62, 76, 121). Additionally, several pathogenic bacteria are known to enter a viable but non-culturable (VBNC) state which is provoked by certain environmental stimuli. These cells may still have an important role as pathogens, yet they cannot be detected by routine culture procedures. Therefore, during certain times of the year false negative results for the presence of particular pathogens may be common. A shift in monitoring practices and methods of detection is necessary to overcome these problems. New detection techniques, specific to pathogenic bacteria, show promise and are preferable to antiquated indicator methods.

Immuno-detection methods have been successfully used for the detection of *Salmonella*, *V. vulnificus* and *V. cholerae*. Enzyme-linked immunosorbent assay (ELISA) using monoclonal antibodies was used to detect *Salmonella* Paratyphi in prawns. The total assay time was 20 hours, which is much shorter than with standard cultivation (65). *V. vulnificus* and *V. cholerae* can be directly detected in oyster tissues by immunoelectron microscopy (2).

The most promising of the new detection methods are based on molecular techniques. DNA hybridisation and the polymerase chain reaction (PCR) have been used to isolate pathogens from a variety of sources. A major advantage of these techniques is specificity for particular pathogens, sensitivity (detection of one cell is not uncommon) and speed (most assays are complete within a few hours). As few as 1-10 *Salmonella* cells per gram of oyster meat have been detected by PCR in seeded samples (8). Similar recoveries have also been shown for *Vibrio* spp. in water samples (4, 12, 29). *V. vulnificus*, *V. cholerae* and *V. parahaemolyticus* have also been detected by PCR in shellfish tissues (34). The limit of detection is greater for these samples (100-1,800 cells per gram) (28, 51). This difference is due to the inhibitory properties of oyster tissue on the PCR.
Besides rapid detection and excellent sensitivity, a major advantage in using molecular detection methods is that these are not limited to culturable bacteria. The levels of total bacteria, both culturable and VBNC, can be obtained. Coleman and Oliver (29) optimised the PCR to detect VBNC V. vulnificus in water samples. The limit of detection was 10 cells. If viable but non-culturable cells are prevalent, the number of cycles in the PCR must be nearly doubled. Approximately 500 times more DNA from VBNC cells is necessary to view bands by gel electrophoresis (11, 29).

Viruses
Williams and Fout (120) have reviewed methods for the recovery and detection of viruses from shellfish. Both extraction and concentration, as well as adsorption-elution-concentration procedures, have been developed to recover viruses. The efficiency of the methods for recovery may range from 2% to 47%. While cell culture systems have been widely used for the detection of viable viruses, these detect and quantify only a fraction of the hundreds of viruses present in wastewater or contaminated coastal water and shellfish. As previously mentioned for the bacteria, new procedures, such as PCR amplification of target viral genomes, provide more rapid, specific and sensitive approaches for detection of viruses, especially the fastidious viruses (i.e., HAV and Norwalk virus) (58, 68, 69, 70). Routine assessment of water, sediments and shellfish with PCR will have to address in the future both the inhibition and potential detection of inactivated viruses. However, as a tool for undertaking vulnerability, PCR can provide a broader assessment of viruses present and the potential for exposure. During the investigation of an outbreak of HAV associated with the consumption of raw oysters, PCR was used to detect the presence of HAV in oysters and scallops from both unapproved and approved waters. PCR has now been used for SRSV as well as Norwalk virus in shellfish (6, 35, 69, 70).

Toxins
For detection of natural toxins, a mouse assay system has been used, although an immunoassay method has been adopted in certain situations. A useful method for the future would be to screen for the micro-organisms rather than the toxin itself. For scombroid poisoning, 87% of cases were associated with inadequate refrigeration, therefore regrowth models associated with various temperature-abuse scenarios are needed for the various enteric bacteria associated with the production of histamine.

Risk assessment
Risk assessment models can be used to examine infectious disease risks from foods and water contaminated with microbial pathogens. The risk of infection is a function of the micro-organism, dose and the host-microbe interaction. This defines a probability of infectivity from a given unit dose; a dose-response function which can be modelled (45). Each pathogen or strain has an intrinsic ability to cause infection or disease. The host population would also influence the model, and a different model might be developed for each population with varying sensitivities to the pathogen. Host factors include general and specific immunity, genetic factors, age, sex and other underlying diseases or conditions which might influence susceptibility.

Exposure depends on the initial concentration of the pathogen in the food or water, processes which would decrease the numbers (i.e. wastewater treatment) and environmental conditions which would influence microbial survival or potentially the regrowth. The final level of the pathogen in the food or water and the amount or volume consumed determine the risk of exposure.

This type of assessment has been used for shellfish harvested from approved waters in the USA (88, 106).

Using echovirus-12 and rotavirus probability models, the individual risk has been determined for consumption of raw shellfish. Individuals consuming a single serving of raw shellfish from approved waters in the USA may have a 1/100 probability of becoming infected with a moderately infectious enteric virus. However, the risk of infection becomes a 1/2 probability (with a lower 95% confidence limit of a 2/5 risk) if exposed to a highly infectious virus, such as the rotavirus, at an average virus exposure of 6 PFU/60 g (Fig. 9).

![Fig. 9](image-url) Risk of viral infection from consumption of raw shellfish using dose-response modelling and monitoring data (106)

The risk of infection is the initial step in microbial dose-response assessment. Estimates of morbidity and mortality can then be made from the infectivity estimates based on asymptomatic to symptomatic ratios and case/fatality ratios for various pathogens. Secondary and tertiary transmission by a person-to-person route should also
be taken into account. Finally, the overall risk must be assessed in comparison to other relative risks.

More data are required on the occurrence and exposure for the various microbial hazards associated with seafood. These data, along with dose-response models, can be used for risk assessment and can be fed into the HACCP approach as control data, so that the most cost-effective and reliable strategy for reducing risks and improving seafood safety for any particular hazard or geographical location can be more adequately defined and prioritised. Significant data gaps can be identified and research can be supported to address the greatest uncertainties.

For routine work, the use of faecal indicators to predict a relative level of faecal contamination should not be disposed of. However, the main source of seafood illness is species which are not predicted by these organisms. In order to ensure public health, routine surveillance using pathogen-specific techniques should be implemented. This, in combination with risk assessment and HACCP, will begin to address the improvements needed for enhancing the safety of seafood.

Conclusion

Scombroid illness appears to be the greatest cause of seafood-associated disease linked to post-harvest contamination and improper storage of fish, and is caused by a variety of enteric bacteria.

Viruses such as the small round structured viruses (SRSV) are an emerging concern associated with the consumption of shellfish. Better protection of harvesting waters is imperative as many outbreaks have been associated with cooked or depurated products.

Sensitive populations, such as the immuno-compromised, diabetics and those with impaired liver functions, are at an increased risk of severe outcomes from infection with *Vibrio* spp. These groups are also at increased risk of death due to such organisms.

Indicator bacteria are inadequate to protect the consumer against enteric viruses carried in seafood.

New methods allow for determination of contamination and exposure to be used in conjunction with risk assessment and identification of critical control points.

*Vibrio* spp. account for the highest number of infections of known bacterial aetiology from shellfish consumption. As naturally-occurring bacteria, *Vibrio* spp. cannot be eliminated from the source, therefore the most practical measures to minimise human infection include strict guidelines against temperature abuse, consumer education and better detection.

The occurrence of microbial pathogens and natural toxins in fish and shellfish harvested in one geographical area can have an impact on many geographically distinct populations as a result of widespread distribution and transport of seafoods, and the problem will not be rectified without the implementation of increased sanitation practices.

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Le rôle des poissons et des fruits de mer dans les toxi-infections alimentaires aux États-Unis d'Amérique

E.K. Lipp & J.B. Rose

Résumé

Aux États-Unis d'Amérique, de 1983 à 1992, les poissons et fruits de mer occupaient le troisième rang parmi les catégories d'aliments responsables de toxi-infections alimentaires. S'agissant de la consommation de poissons, les vecteurs ou agents le plus souvent incriminés étaient des poissons scombridés, des ciguatoxines, des bactéries et d'autres agents indéterminés ; concernant les mollusques et crustacés, les toxi-infections étaient dues à des agents indéterminés, aux agents de l'intoxication paralytiques des mollusques et crustacés, à *Vibrio* spp. et à d'autres bactéries, suivis par le virus de l'hépatite A. On dénombre au moins dix genres de bactéries responsables de toxi-infections alimentaires transmises par les fruits de mer. Au cours des 25 dernières années,
les agents bactériens associés à une contamination fécale n'ont représenté que 4 % des maladies liées à la consommation de mollusques et crustacés, tandis que les bactéries endogènes représentaient 20 % des toxi-infections alimentaires et étaient responsables de 99 % des décès. La plupart des ces bactéries indigènes appartiennent à la famille des Vibrionaceae qui comprend les genres *Vibrio*, *Aeromonas* et *Plesiomonas*. En général, *Vibrio* spp. n'est pas associé à des contaminations fécales ; aussi n'y a-t-il pas de corrélation entre les indicateurs de cette contamination et la présence de *Vibrio*. Les virus sont la principale cause de toxi-infections associées à la consommation de mollusques et de crustacés : par exemple, entre 1981 et 1992, sur 196 foyers signalés dans l'État de New York, 33 % étaient dus au virus de Norwalk et 62 à des virus gastro-intestinaux (petits virus à structure arrondie). De plus, plusieurs maladies résultent d'une efflorescence toxique des algues, du développement de bactéries endogènes et de diatomées responsables d'intoxication neurotoxique (*neurotoxic shellfish poisoning*), d'intoxication paralysante (*paralytic shellfish poisoning*), d'intoxication diarrhéique (*diarrhoetic shellfish poisoning*), d'intoxication avec effet d'amnésie (*amnesic shellfish poisoning*), ainsi que de ciguatera. D'après les estimations actuelles, on dénombre 20 000 cas de ciguatera chaque année dans le monde.

L'intoxication par l'histamine (intoxication par les scombridés) est la première cause de toxi-infection alimentaire associée à la consommation de poissons et de fruits de mer. La scombrotoxine est d'origine bactérienne avec, à la source, des vibrions halophiles induisant des niveaux élevés d'histamine. L'intoxication par l'histamine varie selon les régions géographiques, et plusieurs espèces sont impliquées, notamment le thon, le mahi-mahi, le tassergal, la sardine, le maquereau, la sériole et l'ormeau. Une température excessive est reconnue comme le principal facteur favorisant l'intoxication par l'histamine.

Dans la pratique, il ne faut pas négliger l'étude des indicateurs fécaux pour évaluer le niveau relatif de contamination. Toutefois, les espèces à l'origine des principales intoxications par les fruits de mer ne peuvent être détectées par le simple recours à ces indicateurs fécaux. Pour protéger la santé publique, une surveillance régulière, basée sur de nouvelles techniques spécifiques à un agent pathogène, telles que l'amplification en chaîne par polymérase, devrait être mise en œuvre. Ces techniques, ajoutées à l'évaluation des risques et à la méthode de l'analyse des risques, points critiques pour leur maîtrise, permettront de garantir l'innocuité des poissons et des fruits de mer pour l'homme.

**Mots-clés**

desconocidos; en cuanto al marisco, agentes desconocidos, el envenenamiento paralítico por marisco, *Vibrio* spp. y otras bacterias, seguidos por el virus de la hepatitis A, fueron las causas de las toxi-infecciones registradas. Hay por lo menos diez géneros de patógenos bacterianos involucrados en toxi-infecciones alimentarias asociadas al consumo de mariscos. En el curso de los últimos 25 años, los patógenos bacterianos asociados con la contaminación fecal estuvieron implicados en sólo el 4% de los brotes relacionados con marisco, mientras que la flora bacteriana endógena daba cuenta del 20% de las afecciones y del 99% de las muertes. La mayoría de esas bacterias indígenas pertenecen a la familia Vibrionaceae, que comprende a los géneros *Vibrio, Aeromonas* y *Plesiomonas*. *Vibrio* spp. no suele venir asociado a la contaminación fecal, por lo que los indicadores de ese tipo de contaminación no presentan correlación con la presencia de *Vibrio*. Los virus constituyen la causa más frecuente de toxi-infecciones asociadas al marisco: por ejemplo, en el Estado de Nueva York, entre 1981 y 1992, de un total de 196 brotes, un 33% y un 62% fueron causados respectivamente por el virus de Norwalk y por virus gastrointestinales (pequeños virus de estructura globular). Por otra parte, diversas enfermedades son consecuencia de florescencias tóxicas de algas, del crecimiento de flora bacteriana endógena y de diatomeas que causan envenenamiento neurotóxico (*neurotoxic shellfish poisoning*), envenenamiento paralítico (*paralytic shellfish poisoning*), envenenamiento diarreico (*diarrhoetic shellfish poisoning*), envenenamiento amnésico (*amnesic shellfish poisoning*) y ciguatera. Las estimaciones actuales cifran en 20.000 el número de casos anuales de ciguatera en el mundo.

La toxicidad histamínica (envenenamiento de escómbridos) constituye la causa más importante de toxi-infecciones ligadas al consumo de productos marinos. La escombrotoxina, de origen bacteriano, es causada por *Vibrio* spp. halóficos que provocan una elevación de los niveles de histamina. Las características del envenenamiento de escómbridos varían geográficamente, y son numerosas las especies involucradas, a saber: el atún, el mahi-mahi, la anjova, la sardina, la caballa, el pez limón y la oreja de mar. Una de las principales causas de envenenamiento de escómbridos que suele citarse es el exceso de temperatura. En la práctica, no se debe descartar el estudio de indicadores fecales para predecir el nivel relativo de contaminación; sin embargo, gran parte de las especies responsables de toxi-infecciones alimentarias debidas al consumo de mariscos no pueden ser detectadas mediante estos indicadores fecales. Velar eficazmente por la salud pública exigiría aplicar una vigilancia sistemática basada en nuevas técnicas de detección específica de patógenos, como la reacción en cadena de la polimerasa. El uso de tales técnicas, combinado con el de métodos de evaluación de riesgos y de análisis de riesgos y control de puntos críticos, constituía un primer paso hacia la necesaria mejora del nivel de seguridad que ofrecen los alimentos de origen marino.

**Palabras clave**

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