

Shellfish-Associated Viral Disease Outbreaks

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1.0. INTRODUCTION

Enteric viruses include a broad array of pathogens that enter the host via the fecal-oral route, often through the ingestion of sewage-contaminated food or water. In young children, many illnesses can result from fomites shared among playmates. The enteric viruses include the calciviruses, which are classified as noroviruses and sapoviruses; picornaviruses, particularly hepatitis A virus, the Aichi virus, and poliovirus; hepatitis E virus; astroviruses; rotaviruses; enteric adenoviruses; coronaviruses and toroviruses; and picobirnaviruses. The most frequently reported food-borne outbreaks are caused by noroviruses, formerly called the agent of winter vomiting disease, Norwalk-like viruses, and small round structured viruses (SRSVs). Hepatitis A virus is also reported as a frequent cause of food-borne illness. Children are infected in early childhood with group A rotaviruses, enteric adenoviruses, astroviruses, and calciviruses and may develop partial immunity against them (Glass et al., 2001). These so-called childhood viruses may be transmitted easily from child-to-child through casual contact and through fomites.

Enteric viruses have undoubtedly been infecting mankind since the dawn of civilization; however, techniques to isolate and identify these viruses were not developed until the past century. With the advent of sensitive molecular methods, even nonpropagable viruses may now be detected. In spite of these advances, reporting of enteric viral illnesses is poor or nonexistent in many parts of the world today. Noroviruses are believed to constitute the most frequent cause of food-borne illness; however, only major outbreaks are recorded and accurate, quantitative assessment of the number of individuals affected is not available. The best data are available for poliovirus, which has nearly been eradicated through global vaccination and tracking programs. Accountability for hepatitis A and hepatitis E infections is fair in the developed nations, due to the potential seriousness of diseases caused by these agents. However, the incidence of norovirus, sapovirus, rotavirus, astrovirus, and other viral pathogens is not generally recorded, except in outbreaks involving high numbers of individuals or those involving politically or socially important individuals. This is because these viruses seldom cause mortality even though they are the most prevalent causes of food-borne illnesses in the world today. When illnesses are noted, there is seldom epidemiological follow-up to confirm the cause of illness. Most of the

illnesses are likely from drinking sewage-contaminated water, followed by the consumption of raw or undercooked foods that were tainted by contaminated water, the hands of food-handlers, or contaminated contact surfaces.

Among the most notable foods that may contain enteric viruses are molluscan shellfish (oysters, clams, mussels, cockles), especially when they are consumed raw or lightly cooked. The shellfish accumulate contaminants, including enteric viruses, from the water and bioconcentrate them within their edible tissues. Consequently, some large outbreaks of hepatitis A and noroviruses have been reported after consumption of contaminated shellfish. Efforts to document such outbreaks have provided some glimmer of the causes and effects of shellfish-borne disease but do not convey the magnitude of the problem (Gerba and Goyal, 1978; Richards, 1985, 1987; Rippey, 1994). The Centers for Disease Control and Prevention have indicated that noroviruses are the most common cause of acute gastroenteritis in the United States, causing an estimated 23 million cases annually with 9.2 million of those cases associated with foods (Mead et al., 1999). The vast majority of illnesses go undiagnosed, and statistics are not maintained on those reported because norovirus illness is not a notifiable disease in most countries including the United States.

Although persons infected with norovirus develop acute vomiting and diarrhea, symptoms are fleeting, lasting only a day or two. Consequently, the patients do not seek medical attention because symptoms resolve rapidly and spontaneously. They may spread the disease to family members through contamination of surfaces or by handling foods with inadequately sanitized hands. Such individuals often miss work for 2 or 3 days, but when they return, they may still carry the virus and be a source of infection to their work mates (White et al., 1986, Iversen et al., 1987; Haruki et al., 1991; Graham et al., 1994; Richards et al., 2004).

The scientific literature is dotted with occasional reports of outbreaks, particularly for hepatitis A and the noroviruses. Epidemiological linkage of an outbreak to a particular source is more difficult for some virus infections due to differences in incubation times. For instance, hepatitis A has an extended incubation period approaching 1 month, and sick individuals may not be able to say with any degree of certainty where or what they ate a month earlier. Larger outbreaks are more likely to reveal the source of infection, be it water, food, or a particular restaurant. Illnesses due to norovirus and sapovirus are easier to track because of their short, 1- to 2-day incubation period. Rotavirus causes diarrhea in infants and young children and, although it may be transmitted by foods, children develop immunity to rotavirus at an early age. Rotavirus diarrhea may lead to dehydration and vascular collapse, particularly when rehydration therapy is not available. Although rotavirus is transmitted by the fecal-oral route, it is likely that most illnesses are from direct contact of children with other children and fomites, rather than through the food-borne route. Astrovirus is another pathogen that has been difficult to track. Molecular diagnostic methods are now avail-

able for astroviruses, which may allow some screening of foods for the virus, especially in outbreak investigations.

2.0. CASE STUDIES

Because reporting of viral illnesses and their association with a particular food are inadequate at best, this chapter will not attempt to tabulate and list outbreaks by country or food source; rather, the focus will be to highlight specific, shellfish-related outbreaks in countries around the globe and to indicate sources of contamination, when known. This section highlights outbreaks caused by known shellfish-borne viral pathogens.

2.1. Hepatitis A Virus:

The United States has experienced numerous outbreaks of shellfish-associated hepatitis A. Major outbreaks date back to 1961 with 459 cases in New Jersey and New York from clams, 372 cases in Pennsylvania, Connecticut, and Rhode Island in 1964 from clams, and 293 cases in Georgia, Missouri, New Mexico, Oklahoma, and Texas in 1973 from the consumption of oysters from Louisiana (Richards, 1985). Oysters associated with the 1973 outbreaks were consumed raw but were reportedly obtained from waters that met the standards of the National Shellfish Sanitation Program (Portnoy et al., 1975; Mackowiak et al., 1976). Flooding of polluted water from the Mississippi River into oyster growing waters occurred 2 months earlier and may have been responsible for the outbreaks (Portnoy et al., 1975; Mackowiak et al., 1976). A multistate outbreak of hepatitis A was attributed to the consumption of raw oysters from Florida (Desconclois et al., 1991). The attack rate was calculated at 19 persons per 10,000 dozen oysters consumed in restaurants.

The largest outbreak of hepatitis A occurred in and around Shanghai, China, from January through March, 1988. More than 293,000 individuals became ill after eating clams harvested from recently opened mud flats outside of Shanghai (Xu et al., 1992) with 47 deaths reported (Cooksley, 2000). Most of the cases were reported to have been from direct consumption of the clams, rather than from person-to-person transmission. Since the incubation period for hepatitis A is around 30 days, many people ate the clams before any symptoms appeared. During this same period, factory workers in Shanghai also developed hepatitis A after eating raw and cooked clams (Wang et al., 1990; Halliday et al., 1991; Tang et al., 1991). Because thorough cooking is known to inactivate enteric viruses, it appears that the clams were not fully cooked. Chinese clams imported into the United States were recently found to contain hepatitis A virus using molecular biological methods (Kingsley et al., 2002b). Although import regulations require that clams from China be cooked for importation, these clams were only labeled as cooked, but had the appearance of raw product. They were associated with an outbreak of norovirus in New York State (see below). Clams imported

into Japan from China also were associated with outbreaks of hepatitis A (Furuta et al., 2003). Between 1976 and 1985, there were 109 cases of hepatitis A reported in Japan and 11% were believed to be from consuming raw shellfish (Konno et al., 1983; Kiyosawa et al., 1987). Another study reported 225 cases of hepatitis A in Japan and raw oysters were the likely vehicle for infection (Fujiyama et al., 1985).

In 1997, 467 cases of hepatitis A occurred in New South Wales, Australia, from the consumption of oysters harvested from Wallis Lake (Conaty et al., 2000). One person died from hepatitis and a class action suit was filed on behalf of the victim and those who became ill. Before marketing, the government of New South Wales required that all shellfish be subjected to the commercial process of depuration, where shellfish are placed in tanks of clean seawater and are allowed to purge contaminants for 2–3 days. Depuration has been shown to be effective in eliminating many bacterial pathogens and spoilage organisms from molluscan shellfish but not enteric viruses such as hepatitis A and noroviruses (Richards, 1988, 1991; Kingsley and Richards, 2003). Long-term relaying (Richards, 1988) may be a better alternative to the commercial depuration of viruses from shellfish.

Europe too has had its share of hepatitis A associated with contaminated shellfish. Outbreaks of hepatitis A from oysters, cockles, and mussels have been reported in England, Wales, and Ireland (O'Mahony et al., 1983; Polakoff, 1990; Maguire et al., 1992). Shellfish-associated hepatitis A has also been reported in Italy. One outbreak was from imported clams with secondary spread to a public school (Leoni et al., 1998). The total cost of one outbreak of hepatitis A involving 5,889 cases in Italy was estimated at \$24 million and costs to a sick individual were estimated at \$662 (Lucioni et al., 1998). Spain experienced hepatitis A outbreaks in 1999 with 184 cases from clams meeting European Union standards (Sanchez et al., 2002). Clams imported from Peru also led to 183 cases of hepatitis A in Valencia with hepatitis A virus detected in 75% of the shellfish samples tested (Bosch et al., 2001). A survey of South American imports showed the presence of hepatitis A virus in 4 of 17 lots of molluscs (Romalde et al., 2001).

2.2. Noroviruses

Shellfish-borne outbreaks of norovirus have been widespread. A review of the literature indicates 6,049 documented cases of shellfish-associated gastroenteritis in the United States between 1934 and 1984 (Richards, 1987). Because no bacterial pathogens were associated with these illnesses and symptomatology was consistent with norovirus illness, it seems likely that noroviruses were the causative agents. One outbreak involved 472 cases of gastroenteritis from the consumption of Louisiana oysters. This outbreak resulted in 25% of Louisiana's 250,000 acres of shellfish beds being closed, an estimated loss to the industry of \$5.5 million, and disruption of harvesting for 500 licensed oystermen (Richards, 1985). Some outbreaks were small, such as the one in Florida in 1980 involving only six individuals who ate raw oysters (Gunn et al., 1982). In another case, oysters from a defined area in

Louisiana were associated with outbreaks of norovirus illness in at least five states: Louisiana, Maryland, Mississippi, North Carolina, and Florida (Centers for Disease Control, 1993). Although these oysters were distributed throughout the United States, outbreaks were identified only in these five states. Identification of the source of contaminated shellfish was facilitated by tags (labels) on sacks of oysters indicating the location of harvest.

The worst year on record for norovirus outbreaks in the United States was 1983 when New York experienced numerous outbreaks of norovirus illness from raw and steamed clams (Centers for Disease Control, 1982; New York State Department of Health, 1983) and from oysters (Morse et al., 1986). At least 441 people suffered acute gastroenteritis and eight of these individuals subsequently developed hepatitis A as well. Ten outbreaks during the summer were attributed to the illegal harvesting of oysters by an unlicensed digger in polluted waters that were closed to shellfishing along the Massachusetts coast (Morse et al., 1986). Other contaminated shellfish were obtained from Rhode Island waters. Another series of outbreaks in the winter was from clams harvested in New York waters. Negative publicity and the lack of confidence in the safety of local shellfish prompted shellfish dealers to obtain clams that had been depurated in England. Unfortunately, these clams led to more than 2,000 illnesses in 14 separate outbreaks in New York and New Jersey over a 3-month period (Richards, 1985). Clams served at a picnic were responsible for more than 1,100 cases of norovirus illness in one outbreak. The U.S. Food and Drug Administration investigated the outbreaks and concluded that depuration was poorly monitored in plants from which the shellfish were obtained (Food and Drug Administration, 1983).

An outbreak of norovirus illness occurred in 1983 in Rochester, New York. A survey indicated that 84 (43%) of 196 people interviewed contracted norovirus-like illness after eating "cooked" clams served at a clambake. The clams were harvested off the coast of Massachusetts from waters known to be contaminated by untreated municipal sewage (Truman et al., 1987). This outbreak may have been avoided if the clams had been fully cooked or if the shellfish had been obtained from waters meeting the standards of the National Shellfish Sanitation Program. Other U.S. outbreaks of norovirus have been associated with cooked oysters (Kirkland et al., 1996; McDonnell et al., 1997). In an outbreak of norovirus illness that affected 129 individuals in Florida in 1995, surveys indicated that sick individuals had eaten raw, cooked, and thoroughly cooked oysters (McDonnell et al., 1997). Those who reported eating only thoroughly cooked oysters made a subjective judgment and the actual degree of cooking remains unknown. It is unlikely that thoroughly cooked oysters would cause illness unless they were recontaminated after cooking, perhaps with dirty gloves used during shucking or with contaminated shucking knives. There was speculation that the source of norovirus contamination was the overboard dumping of feces during a community-wide outbreak of gastroenteritis (McDonnell et al., 1997). This is not the first instance when overboard disposal of feces or vomit led to contami-

nated shellfish beds and outbreaks of illness. Kohn et al. (1995) conducted a survey of crew members from oyster harvesting boats and learned that 85% of the boats disposed of sewage overboard. Although this is against regulations, monitoring for compliance is very difficult. Berg et al. (2000) also reported the overboard disposal of sewage by oyster harvesters in Louisiana as the likely source of contaminated oysters in two or more outbreaks. New Zealand experienced a number of oyster-associated outbreaks of norovirus illness, and overboard disposal of sewage from recreational boats was suggested as a likely source of contamination (Simons et al., 2001).

Using molecular biological methods, our laboratory detected both norovirus and hepatitis A viruses in clams imported to the United States from China (Kingsley et al., 2002b). These clams were implicated in an outbreak of norovirus illness in New York State. Because the clams were labeled and imported as cooked clams on the half shell, the restaurant served them at their buffet without any heating. Subsequent studies revealed that the clams were raw. No individuals were reported to have developed hepatitis A from these clams. Sequence analysis revealed that both norovirus and hepatitis A virus RNAs contained sequences characteristic of Asian strains of these viruses (Kingsley et al., 2002b).

Other countries have battled with shellfish-associated norovirus outbreaks. A widespread outbreak of norovirus illness infecting more than 2,000 people occurred in Australia in 1978 and was subsequently linked to oyster consumption (Murphy et al., 1979; Grohmann et al., 1980). Another outbreak in Australia affected 25 of 28 people who ate raw oysters at a hotel (Linco and Grohmann, 1980). In response to these outbreaks, in 1981 the government of New South Wales, Australia, implemented regulation requiring that all shellfish be subjected to depuration (Ayles, 1991). A study was undertaken to determine whether depurated oysters from two sites in Australia would cause illness in human volunteers (Grohmann et al., 1981). Oysters from one site produced norovirus illness in 52 people, but none from the second site caused illness. Depuration requirements were recently abandoned in New South Wales, since it has become well recognized that enteric viruses persist within shellfish tissues for periods much longer than the duration of commercial depuration. The extended relay of shellfish offers some hope of reducing or eliminating enteric viruses. Oysters were the presumptive vehicle of norovirus transmission to residents of New South Wales and Queensland in a 1996 outbreak involving 97 cases (Stafford et al., 1997). Although New South Wales required depuration and Queensland did not, these outbreaks demonstrate that depurated oysters can transmit enteric viruses just like nondepurated shellfish.

In Japan, oysters and clams have both been associated with norovirus illness. A study of 80 outbreaks of acute gastroenteritis from 1984 to 1987 revealed that 53 outbreaks were associated with the consumption of oysters (Sekine et al., 1989). Clams imported from China caused 22 cases of norovirus illness and four cases of hepatitis A in Japan (Furuta et al., 2003). Both norovirus and hepatitis A virus were detected in these clams. Another

study reported five outbreaks of norovirus illness from eating raw oysters (Otsu, 1999).

Norovirus outbreaks in Europe have also been reported. Cockles were linked to an early outbreak of norovirus illness (Appleton and Pereira, 1977). Raw mussels and clams were the apparent vehicles of transmission for an outbreak of norovirus illness in Italy and a dose-response relationship was observed between the amount of shellfish consumed and illness (Mele et al., 1989). Mussels in a cocktail were responsible for an outbreak at a national convention in the United Kingdom and again a dose-response relationship was noted (Gray and Evans, 1993). English oysters that had been depurated and served at a birthday party caused nine cases of norovirus gastroenteritis (Ang, 1998).

2.3. Hepatitis E Virus

Hepatitis E virus (HEV) is a nonenveloped, positive-strand RNA virus morphologically similar to caliciviruses. Hepatitis E infection occurs via the fecal-oral route and is a major cause of epidemic as well as sporadic viral hepatitis in endemic regions of Asia, the Indian subcontinent, Africa, and the Americas (Velazquez et al., 1990; Arankalle et al., 1994; Clayson et al., 1997; Balayan, 1997). Hepatitis E is less frequently detected in Europe and only a handful of cases have been reported in the United States. In some developing countries, HEV may account for more than 50% of acute viral hepatitis (Balayan, 1997; Clayson et al., 1997). Like hepatitis A virus, HEV normally causes an acute, self-limiting disease with a low mortality rate; however, during pregnancy a mortality rate between 15% and 25% has been reported (Mast and Krawczynski, 1996). Epidemiological studies have shown that HEV transmission occurs mostly by ingestion of contaminated water (Arankalle et al., 1994; Bayalan, 1997), with few significant contributions of person-to-person or food-borne transmission established to date. Shellfish consumption was considered a risk factor for sporadic cases of hepatitis E in Eastern Sicily (Capopardo et al., 1997), and undercooked cockles and muscles were associated with hepatitis E in India (Tomar, 1998). Epidemiological follow-up is difficult with this virus because of a 15- to 60-day incubation period and the sporadic distribution of illnesses. To date, no large outbreaks of shellfish-associated hepatitis E have been reported. Hepatitis E virus should be considered a potential emerging pathogen in the United States and other countries.

3.0. OUTBREAK PREVENTION

3.1. Monitoring and Regulations

The United States and the European Union have implemented criteria for the harvesting and processing of molluscan shellfish. Under the guidelines of the National Shellfish Sanitation Program (NSSP) Model Ordinance (Anon., 1999) and the NSSP Manual of Operations, shellfish harvesting in

the United States has been historically based on water quality criteria derived from sanitary surveys of shellfish growing water. The surveys are based on the levels of total or fecal coliforms in water and are determined during periodic water sampling and testing. Water testing has served the country well since its implementation in 1925 (Frost, 1925). Sanitary surveys were originally undertaken to reduce the incidence of typhoid fever among shellfish consumers and a successful outcome was achieved. Today, shellfish growing waters are classified as approved, conditionally approved, restricted, conditionally restricted, or prohibited, depending on the level of coliform contamination.

According to the Model Ordinance (Anon., 1999), shellfish obtained from waters with a most probable number (MPN) of fecal coliforms <14/100 ml are classified as approved for shellfish harvesting and direct sale. Shellfish waters are classified as restricted if the fecal coliform levels are under 88/100 ml, while shellfish are prohibited from harvest when the waters have >88 fecal coliforms/100 ml. Because water classification is an ongoing process and the history of a site can be determined by an examination of past data, some areas with intermittent contamination may be classified as conditionally approved and conditionally restricted. Such waters come under a management plan and shellfish are permitted to be harvested for direct sale or for depuration or relaying when the criteria of the plan are met. Shellfish from restricted areas can be harvested only if they are subjected to depuration or relaying before they enter the marketplace. Shellfish from prohibited areas may never be harvested or marketed.

In contrast, the EU follows Council Directive 91/492/EEC (Anon., 1991), which regulates shellfish based on the levels of fecal coliforms or *E. coli* in the shellfish meats, rather than in shellfish growing waters. Under this system, shellfish meats are classified in any of four categories: A, B, C, or D, as shown in Table 9.1. The numbers of fecal coliforms and *E. coli* are also determined by MPN, but the results are reported per 100 g of shellfish meat. The differences between the U.S. and EU standards are, in large part, due to the fact that there are many shellfish growing waters in the United States that are perceived to be clean enough for direct harvest and sale of shellfish,

Table 9.1 Council Directives for the Production and Marketing of Shellfish According to European Union Standards Based on Fecal Coliform or *E. coli* Levels in the Meats^a

<i>Classification</i>	<i>Fecal Coliform Limit</i>	<i>E. coli Limit</i>
A. Sell without processing	<300 MPN/100 g	<230 MPN/100 g
B. Depurate or relay	<6,000 MPN/100 g	<4,600 MPN/100 g
C. Prolonged relay	<60,000 MPN/100 g	N.A.
D. Prohibited	>60,000 MPN/100 g	N.A.

N.A., not applicable; MPN, most probable number.

^a From Anon., 1991.

whereas, water quality is seldom adequate in Europe for direct shellfish harvest and sale. Hence, most shellfish in the EU must be depurated or relayed before they can be marketed whereas depuration is seldom required in the United States. Regardless of which standard is used, the levels of fecal coliforms are not a good indicator of the virological quality of shellfish, because enteric viruses persist longer than coliforms within shellfish tissues and they depurate poorly. Therefore, reliance on coliforms as a predictive index for virus presence is ineffectual. Only when coliform levels are high do the standards prevent the direct sale of potentially virus-laden shellfish. Viruses tend to be more resilient than coliforms to the effects of sewage treatment processes and environmental stressors; therefore, water containing low or negligible levels of coliforms, because of effective inactivation, may contain high levels of enteric viruses.

Shellfish growing waters are often affected by the disposal of sewage from commercial and recreational vessels (Kohn et al., 1995; McDonnell et al., 1997; Simons et al., 2001), leading to sporadic contamination events that are difficult to assess by either the U.S. or EU methods. Neither method is fool-proof. When the incidence of hepatitis A was assessed after an outbreak in Florida, it was established that the attack rate in seafood establishments was 1.9 per 1,000 dozen oysters eaten (Desenclos et al., 1991). Such low-level contamination would likely miss detection using the EU meat standard, because of the low numbers of samples tested, the likely randomness of the contamination, and the lack of correlation between coliforms and enteric viruses within the meats. The utility of the water standard is also limited by the lack of correlation between coliforms and viruses, the generally lower numbers of coliforms (and viruses) in the water compared with the meats, and the lack of homogeneity of the water due to tides, winds, currents, and non-point-source contamination events.

3.2. Enhanced Monitoring and Enforcement

Several areas are in need of better monitoring and enforcement if outbreaks are to be reduced. Tighter enforcement of laws against dumping waste in shellfish harvesting areas would reduce the incidence of enteric virus illness. An area in need of enhanced monitoring is the illegal practice of harvesting shellfish from closed areas, a practice called poaching or bootlegging. Some outbreaks have been attributed to the sale and consumption of poached or bootlegged shellfish (Morse et al., 1986; Desenclos et al., 1991). Typically, the penalties for those who perpetrate such crimes have been relatively small. According to U.S. and EU guidelines, all lots of shellfish must contain tags (U.S.) or health marks (EU), which label the lot with information that allows the shellfish to be tracked to their source. This is important in outbreak investigations as health authorities seek epidemiological evidence to curb the spread of disease. Enhanced monitoring of tags and health marks would serve as a deterrent against poachers.

Tighter enforcement of import laws is needed to restrict the importation of tainted shellfish. Shellfish exported from China, England, Ireland,

Peru, and other countries have been apparent vehicles of enteric virus illness. Exporting countries are required to subscribe to the standards in place for the receiving country. Transactions are often sealed with a memorandum of understanding (MOU) between the exporting and importing nations. Failure to comply with the MOU should impart dire consequences upon the exporting country, including the withdrawal of the MOU in cases that show wanton disregard for the requirements of the agreement. Harvesters, processors, and shippers should meet criteria deemed necessary to ensure the safety of their merchandise. Hazard analysis critical control point (HACCP) plans should be in place to monitor factors that are important in ensuring shellfish safety.

3.3. Improved Sewage Treatment Plants

Another intervention to reduce virus levels in shellfish would be to improve upon sewage treatment plants and septic systems, particularly in coastal regions near rivers, lakes, and shellfish-growing areas. Adequate monitoring and maintenance of treatment facilities are important to reduce viral loads emitted into the environment. The United States routinely chlorinates effluent wastewater and this practice has some penetrating effects on particulate matter that contains potential pathogens. After treatment, the chlorine may be inactivated by sodium thiosulfate treatment. In contrast, the EU often uses ultraviolet irradiation to treat sewage effluent. The lack of penetrating ability, particularly in turbid water or in water containing particulate matter, and the lack of any residual properties imparted by the UV, would be expected to allow some viruses and bacteria to escape inactivation. The technology is available to eliminate or substantially reduce enteric viruses from sewage; however, few if any engineers design sewage treatment facilities with virus reduction in mind. Treatment plant maintenance and operation should be tightly controlled so that the facility works at optimal efficiency.

3.4. Analytical Techniques

Direct monitoring for viruses in water or shellfish should be encouraged using molecular biological methods, namely reverse transcription-polymerase chain reaction (RT-PCR). New RT-PCR protocols continue to be developed along with improved methods to extract the viruses from water and shellfish. Such methods are limited in their practical application because they fail to differentiate infectious from noninfectious viruses (Richards, 1999). Direct assays for infectious viruses would be desirable; however, wild-type hepatitis A and E viruses, noroviruses, sapoviruses, and the astroviruses defy cell culture propagation. Rotaviruses are difficult to assay. Because poliovirus is easily propagated in cell cultures, it was proposed as an indicator for the possible presence of other human enteric viruses when vaccine strains were commonly in use (Richards, 1985). The near eradication of poliovirus and the fear that vaccine strains might revert to wild-type strains have prompted the elimination of vaccine distribution in all but a few select

areas. New virus propagation assays are needed to adequately assess shellfish safety from a virological perspective.

3.5. Processing Strategies

Other intervention strategies to reduce or eliminate enteric virus contamination in shellfish should be implemented on multiple fronts. Lessons from previous outbreaks should be heeded. Perhaps the simplest intervention available to consumers is cooking. In most outbreaks, raw or only lightly cooked molluscs appear to be the primary vehicles of infection. Alternative processing strategies, such as irradiation and high hydrostatic pressure processing, have been proposed. The high levels of irradiation required to inactivate enteric viruses from shellfish imparts undesirable flavor characteristics to the meats. On the other hand, high hydrostatic pressure processing for 5 min was shown effective in inactivating 7 log₁₀ of hepatitis A virus and feline calicivirus, a surrogate for the noroviruses (Kingsley et al., 2002a). High pressure inactivates viruses by denaturation of capsid proteins (Kingsley et al., 2002a) and sanitizes the shellfish from bacterial pathogens and spoilage organisms as well. Treated oysters are reported to taste like the raw product.

3.6. Disease Reporting and Epidemiological Follow-Up

Improved reporting and epidemiological follow-up are needed to understand the magnitude of enteric virus illnesses and to reduce the size of outbreaks once they occur. Such reporting has been effective in Italy where 35 participating, local health units link incidence notification with serology and follow-up questionnaires in their surveillance for hepatitis A (Mele et al., 1986, 1997). In a survey of 10 EU countries, eight had national databases for hepatitis A statistics (Lopman et al., 2002). Likewise, the Centers for Disease Control and Prevention have maintained statistics on reported cases of hepatitis A in the United States. Although some countries maintain statistics on the number of cases of hepatitis A reported, few determine the source of the illness due to the high cost for epidemiological follow-up. Norovirus illnesses are not notifiable diseases in most countries, meaning that there are no formal systems to obtain accurate statistics on the number of illnesses.

3.7. Hygienic Practices

Most outbreaks of shellfish-associated viral illness appear to be from shellfish contaminated within their natural environment; however, some cases, particularly those involving cooked shellfish, may actually be from product contamination by shuckers, handlers, or fomites. The contamination of foods by unsanitized hands of food handlers has led to numerous outbreaks of hepatitis A and noroviruses (Richards, 2001). Better enforcement of hand-washing practices may prevent some potential outbreaks from becoming a reality. Likewise, all sanitary standards generally applied in the food industry should be enforced in the shellfish industry, especially on harvesting boats, and in processing plants, transport facilities, and restaurants. Better educa-

tion and monitoring of food handlers are needed to ensure compliance with food sanitation requirements.

4.0. SUMMARY

Numerous outbreaks of shellfish-borne enteric virus illness have been reported worldwide. Most notable among the outbreaks are those involving norovirus illness and hepatitis A. Lessons learned from outbreak investigations indicate that most outbreaks are preventable. Anthropogenic sources of contamination will continue to invade shellfish growing waters, and shellfish, by their very nature, will continue to bioconcentrate these contaminants, including enteric viruses. There is no quick fix for enteric virus contamination of shellfish; however, vigilance on behalf of the industry, regulatory agencies, and the consumer could substantially reduce the incidence of illness. Enhanced monitoring in all areas of shellfish production, harvesting, distribution, and processing would help to reduce viral illnesses. Pollution abatement and improved hygienic practices on behalf of the industry and consumers are needed. New processing and analytical technologies, such as high hydrostatic pressure processing and molecular biological assays, will enhance shellfish safety and continue to provide new avenues to protect the consumer and the industry. Better reporting and epidemiological follow-up of outbreaks are keys to the development of interventions against the food-borne transmission of viral infections.

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