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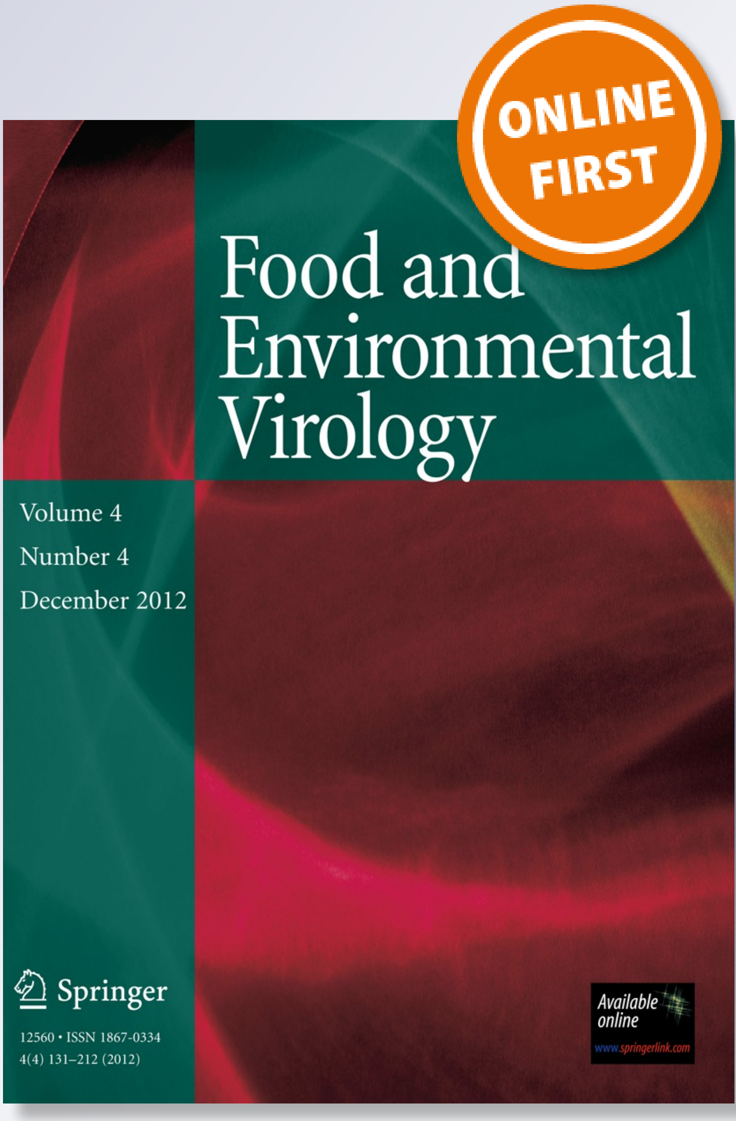

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REVIEW PAPER

Shellfish-Borne Viral Outbreaks: A Systematic Review

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Abstract Investigations of disease outbreaks linked to shellfish consumption have been reported in the scientific literature; however, only few countries systematically collate and report such data through a disease surveillance system. We conducted a systematic review to investigate shellfish-borne viral outbreaks and to explore their distribution in different countries, and to determine if different types of shellfish and viruses are implicated. Six databases (Medline, Embase, Scopus, PubMed, Eurosurveillance Journal and Spingerlink electronic Journal) and a global electronic reporting system (ProMED) were searched from 1980 to July 2012. About 359 shellfish-borne viral outbreaks, alongside with nine ProMED reports, involving shellfish consumption, were identified. The majority of the reported outbreaks were located in East Asia, followed by Europe, America, Oceania, Australia and Africa. More than half of the outbreaks (63.6 %) were reported from Japan. The most common viral pathogens involved were norovirus (83.7 %) and hepatitis A virus (12.8 %). The most frequent type of consumed shellfish which was involved in outbreaks was oysters (58.4 %). Outbreaks following shellfish consumption were often attributed to water contamination by sewage and/or undercooking. Differences in reporting of outbreaks were seen between the scientific literature and ProMED. Consumption of contaminated shellfish represents a risk to public health in both developed and developing countries, but impact will be disproportionate and likely to compound existing health disparities.

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Introduction

An outbreak is commonly defined as the occurrence of cases of illness in a community with a frequency clearly in excess of normal expectancy. The number of cases indicating outbreak occurrence varies according to the infectious agent, size and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence. Therefore, the status of an outbreak is relative to the usual frequency of the disease in the same area, among the same population, at the same season of the year (James 2000).

In recent years, viruses have increasingly been recognized as important causes of outbreaks of foodborne disease (Fleet et al. 2000; Graczyk and Schwab 2000; Parashar and Monroe 2001; Koopmans and Duizer 2004). Certain foods such as ready to eat (e.g., berries and shellfish) can themselves be the source of enteric viruses. In addition, outbreaks can often be foodborne, as a result of infection (including asymptomatic carriage) of a food handler. Norovirus (NV) is currently recognized as the predominant agent of nonbacterial gastroenteritis in humans, which causes foodborne gastroenteritis outbreaks. For NVs, as many as 40 % of infections are estimated to be linked to the consumption of contaminated food. Other enteric viruses, such as rotavirus (RV), astrovirus (AV) and Aichi virus (AiV), had also caused gastroenteritis; with symptoms that are more or less similar to those caused by NVs, but their etiological importance in outbreaks is not really known.

The foods affected by viruses can be classified into two distinct groups, based on the route of contamination. One group includes bivalve shellfish such as oysters, which are contaminated with enteric viruses in their growing sea life (Nishida et al. 2003; Ueki et al. 2004; Cheng et al. 2005; Ueki et al. 2005; Boxman et al. 2006; Saito et al. 2006; Nishida et al. 2007), and the other group includes various kinds of foods other than bivalve shellfish, which are secondarily contaminated with enteric viruses, mainly from infected food handlers, during food processing and/or food serving (Rodríguez-Lázaro et al. 2011). In general, food may be contaminated at different stages of production, such as by fecal contamination of shellfish-growing waters, the use of night soil to fertilize crops, the fecal contamination of water used to wash fruits after harvest or poor hand hygiene by an infected food handler (Le Guyader et al. 2008).

Shellfish are grown in coastal waters of different countries and considered a delicacy in most parts of the world. All bivalve molluscs feed by filtering large amounts of water through their gills. Molluscan shellfish are vectors of bacterial and viral pathogens of seawater origin such as *Salmonella typhi, Vibrio parahaemolyticus, Vibrio vulnificus, hepatitis A virus* and *norovirus*. If pathogenic microorganisms are present in the harvesting waters, shellfish may accumulate these pathogens to levels considerably higher than those in the overlying waters (Burkhardt and Calci 2000). In situ studies with bioaccumulation of viral indicators in oysters have shown that they can concentrate viruses up to 99 times compared with the surrounding water (Westrel et al. 2010).

Viral foodborne outbreaks associated with shellfish consumption have occurred in many countries despite existing strategies to prevent contamination of oyster growing areas. The majority of outbreaks have followed the consumption of raw oysters, although cooked oysters have also been implicated. The short shelf life of oysters has resulted to the fact that most shellfish-borne outbreaks have occurred locally; however, multi-country outbreaks have also been reported (Webby et al. 2007). Epidemiological evidence suggests that human enteric viruses are the most common pathogens transmitted by shellfish. Specifically, NV outbreaks associated with oyster consumption have been well documented worldwide (Baker et al. 2010) and hepatitis A virus infection is the most serious viral infection linked to shellfish consumption, causing a debilitating disease and, occasionally, death. The first documented shellfish-borne outbreak of "infectious hepatitis" occurred in Sweden in 1955, when 629 cases were associated with raw oyster consumption (Pinto et al. 2009). Several shellfish-borne outbreaks have been published. Outbreaks caused by shellfish consumption have the potential to be extensive, particularly where the public health measures are not adequate. Shellfish-borne diseases are expected to rise with increases in extreme rainfall because of the climate change and deterioration in water quality. It is important to establish the current impact of such events on public health to allow future predictions, aid policy formulation and improve adaptive capacity (Cann et al. 2012).

Potasman et al. (2002) published a review of infectious disease outbreaks associated with bivalve shellfish consumption and outlined outbreaks before 2000, with the focus on outbreaks of bacterial origin. To the best of our knowledge, this study is the first global systematic review of shellfish-borne viral outbreaks. The aim was to investigate the shellfish-borne viral outbreaks by geographical area, viral pathogen, outcome, seasonality, frequency and type of shellfish. This systematic review attempts to outline to the community the global dispersion of outbreaks of virus infection associated with shellfish consumption, and also to emphasize the need of taking preventive measures for the decrease of these outbreaks.

Materials and Methods

Classification and Nomenclature

The class Bivalvia, sometimes called Pelecypoda, belongs to the phylum Mollusca, one of the most numerous and oldest groups in the animal kingdom. There are ~8,500 species of marine bivalves. Bivalves, commonly called shellfish, include such molluscs as oysters (*Crassostrea gigas, Crassostera virginica, Ostrea edulis*, *Ostrea concaphila* and *Ostrea lurida*), clams (*Rudiatapes philippari-um, Rudiatapes decussates* and *Donax sp.*), mussels (*Mytilus edulis* and *Perna canalicullus*) and cockles (*Anadara granosa* and *Anadara subcrenata lischke*). They are all characterized by having a bivalve shell joined by an elastic ligament. Within the class, the shell forms are used in classification.

Data Sources and Search Strategy

The PRISMA and ORION statement were used to inform the search and analysis process (Stone et al. 2007; Liberati et al. 2009). Medline, Embase, Scopus, PubMed, Eurosurveillance Journal and Spingerlink electronic journal were the databases used to identify peer-reviewed articles reporting outbreaks associated with bivalve shellfish. Database searches were performed between March and July 2012—however, there has been a continuing reviewing of the database the whole time the reporting of the systematic review took place—using the following search terms and their variations in combination: "outbreaks AND shellfish," "oyster," "infection virus AND shellfish," "hepatitis A outbreak," "imported cases AND shellfish" and "bivalve molluscs AND outbreak." The titles, key words and abstracts of articles included in the online databases were searched for these search terms. The grey literature was also searched using the Program for Monitoring Emerging Diseases (ProMED–mail) using combinations of the key search terms: "oysters AND virus," "shellfish AND outbreaks" and "clams"and "mussels".

Selection Criteria

All study design types were included. Single case reports were not included, unless the case was the primary infection of the outbreak. Non-English language studies were included and translated (except those in Chinese/Japanese). This systematic review included both experimental and nonexperimental studies from 1980 onward. Additional publications, not found in the electronic searches, were also selected from bibliographies of relevant articles. Expert opinion and qualitative studies were excluded. Also, conference abstracts, editorials and letters to the editor were excluded.

The selection criteria developed a priori were the following:

- The number of the cases of the outbreak
- Duration (in months) and season of the outbreak
- Age group of cases
- Symptoms (vomiting, fever, diarrhea, abdominal pain, etc.) according to Kaplan criteria for virus.
- Country of the epidemic
- Country of shellfish origin
- Shellfish species (oysters, clams, mussels, cockles, etc.)
- Shellfish condition (frozen or fresh)
- Viruses involved in the outbreak (noroviruses, hepatitis A virus, hepatitis E virus, astrovirus, Aichi virus, rotavirus, sapovirus, etc.)
- Method of analysis (molecular, immunoassay, culture microbiological method, etc.)

Data Selection

About 61 articles met the inclusion criteria, one of which was not in English (Spanish). All of them were included in the systematic review. All 61 studies fulfilled criteria for case definition of shellfish virus infection. Based on each set of criteria, the number of enrolled individuals was recorded (if this information was provided in the article). To analyze the combined results of the studies, the framework outlined in the PRISMA and ORION statements (Stone et al. 2007; Liberati et al. 2009) was followed for the review process. Outbreak reports and subsequent investigations, including nonrandomized studies, form the main body of evidence regarding risk factors and clinical importance of healthcare-associated infections. Major outcome variables were extracted independently by two investigators into a spreadsheet (Excel, Microsoft) with a standardized approach. Any disagreement was resolved by discussion.

Results

The study selection process is outlined in Fig. 1. The literature search yielded 380 citations (Fig. 1). Only 61 research articles (16 %) met the inclusion criteria and reported on a total of 359 shellfish-borne outbreaks. About 22 articles (22/61, 36 %) were published during the past 5 years. Also, ProMED reported 84 outbreaks associated with oysters consumption, but only 9 (9/84, 10.7 %) outbreaks were of viral origin and were finally included in this study; all the rest were bacterial in origin (Fig. 1).

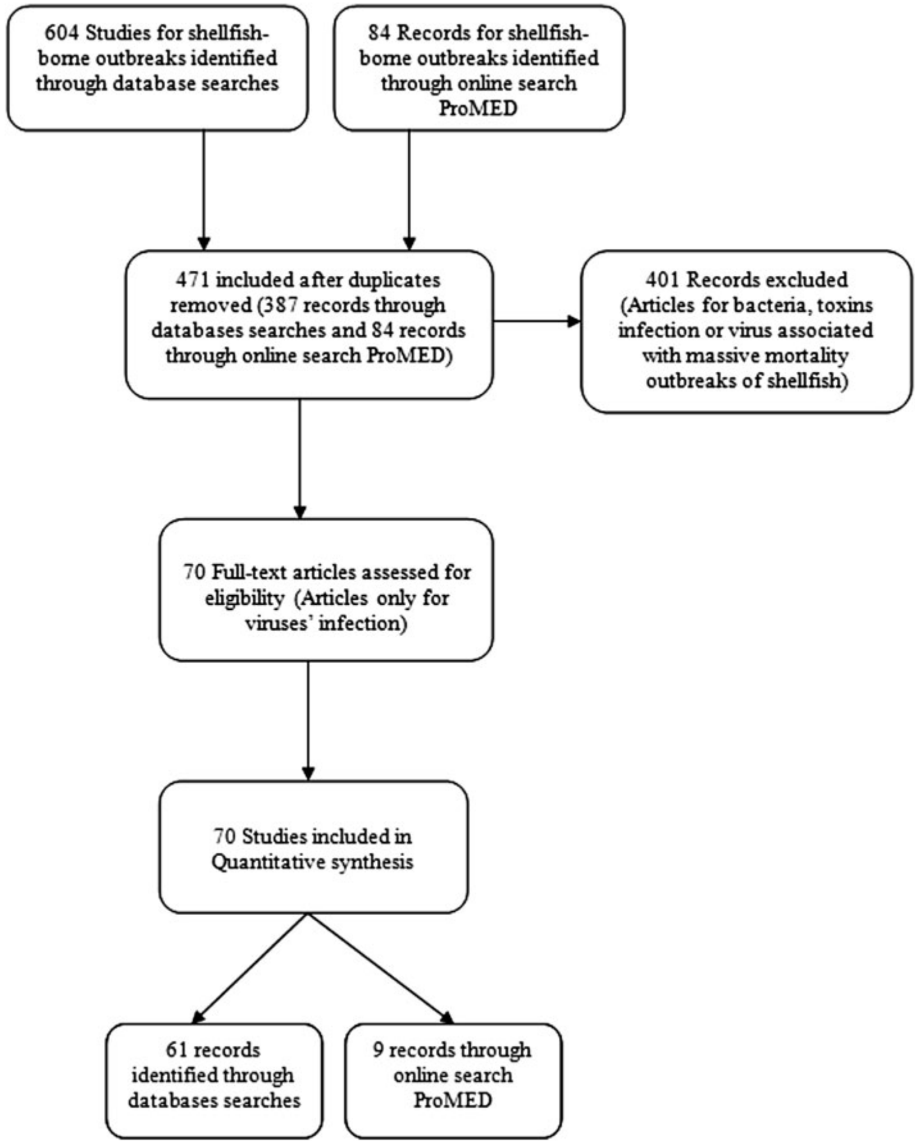
Of the 368 outbreaks associated with shellfish found in the scientific literature and ProMED, 71 (19.3 %) reported the number of cases. The largest outbreak occurred in Shanghai, in 1988. This epidemic involved 290,000 people who contracted hepatitis A after eating clams. In contrast with other bivalve-associated infections, this epidemic is remarkable for the death toll; 47 people died. In the 7.9 % of the outbreaks, the number of the cases was <50, while 5.7 % involved between 51 and 100 people (Graph 1).

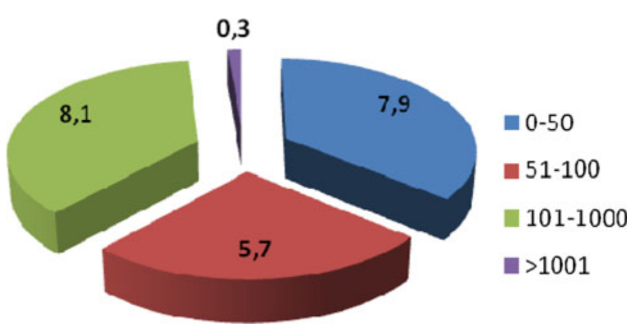
Of the 368 outbreaks, 10.3 % occurred between 2005 and 2012. As it concerned the outbreak duration, 11.7 % of the outbreaks lasted for 1 month, while 6.5 % lasted for >2 months. Also, 9.5 % of the shellfish-borne outbreaks occurred predominately during winter months. A high percentage of the articles (81.5 %) did not report the season of the outbreak. Similarly, a large number of outbreak studies (93.5 %) did not mention the age groups of cases. Only 25 outbreak studies (6.8 %) reported the age group. In all outbreaks, people of all ages were infected.

About 100 outbreaks (27.2 %) presented epidemiological data only, while 160 (43.5 %) carried out both epidemiological and laboratory investigations with shellfish samples analyses. Of the laboratory investigations, 39.7 % used molecular analytical approaches, and 2.7 % immunological methods. Culture microbiological methods of analysis for virus detection in shellfish samples were used in only one study. More than half of the outbreaks (57.3 %) did not report the method of analysis.

The reported outbreaks occurred in 17 different countries between 1980 and 2012 (18 studies documented two or more outbreaks). Geographical distribution of studies was uneven and within geographical regions certain countries were over-represented. The majority of the reported outbreaks were located in East Asia, followed by Europe, America, Oceania, Australia and North Africa

Fig. 1 Study selection process

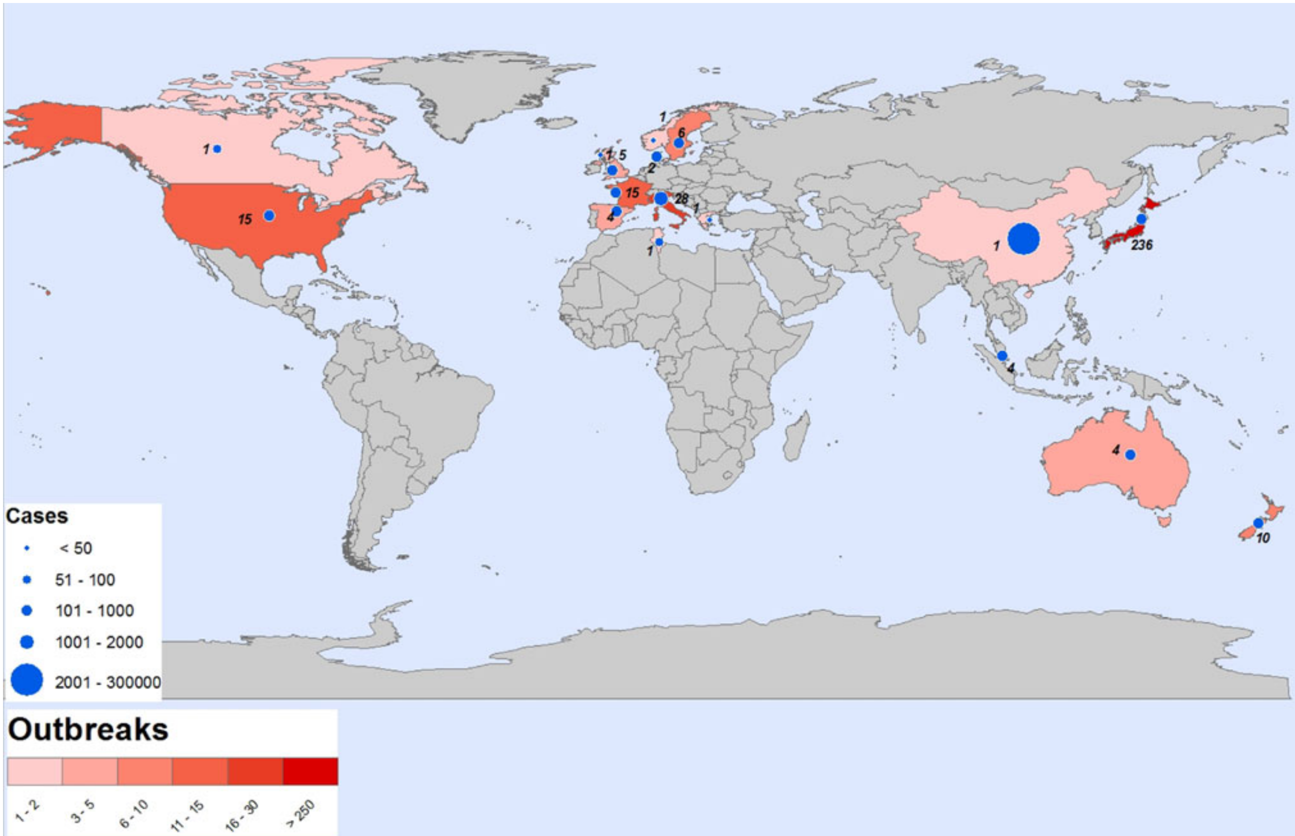




Graph 1 Shellfish-borne viral outbreaks with number of cases

(Map 1). More than half of the outbreaks, 63.6 % were reported in Japan. The rest were reported in Italy (7.7 %), United States of America (4.6 %), France (4.1 %), New Zealand (2.7 %), Sweden (1.6 %), Spain (1.6 %), United Kingdom (1.4 %), Singapore (1.1 %) and Australia (1.1 %). In 8.2 % of the outbreaks, the country of the epidemic was not reported.

The virus types implicated in all outbreaks are listed in Table 1. The most common vehicles of infections were NVs (83.7 %) and HAV (12.8 %). Most reported NV shellfish-borne outbreaks occurred in East Asia (72.7 %), followed by Europe, Oceania, America and Australia, while most reported outbreaks because of HAV were reported in Europe (83 %). In only one study, the hepatitis E virus (HEV) was associated with shellfish consumption and the outbreak occurred in the United Kingdom (March 2008). All other enteric viruses, including rotavirus, astrovirus, Aichi virus and sapovirus, were reported at very low rates. In very few outbreaks, two types of viruses, NVs and sapovirus (0.5 %), NVs and RVs (0.5 %), were simultaneously detected.



Map 1 Global distribution of shellfish-borne outbreaks and gastroenteritis cases

The most common symptoms were vomiting (35.3 %), diarrhea (34.5 %), nausea (31.5 %), fever (31 %) and abdominal pain (30.7 %). The other symptoms were headache, jaundice, muscle aches, weakness, chills, stomach pain, anorexia and sweating. Also, in more than half of the outbreaks (63.3 %) of the cases did not report any specific symptoms.

Shellfish-harvesting areas were located in five continents: America (6 %), Europe (4.4 %), Asia (2.2 %), Oceania (1.6 %) and Australia (0.5 %). Of the outbreaks (85.8 %) did not report the country of the shellfish-harvesting area. Shellfish derived in total from 13 different countries, such as the United States of America, France, Sweden, Italy, United Kingdom, Australia, China, Japan, Netherlands, Korea and Peru.

Shellfish involved in the outbreaks were classified into four species that are listed in Table 2. The most common shellfish types were oysters (58.4 %) and clams (22.6 %). Most reported oyster-borne outbreaks occurred in Asia, followed by Europe, Oceania and Australia, while most reported outbreaks because of clams were reported in Asia and Europe. Two shellfish species (oysters and clams or oysters and cockles) were reported in 0.8 % of the outbreaks. Also, 3 % of the outbreaks were caused by frozen shellfish.

Discussion

This review has a number of limitations which can be categorized in two groups; systematic review limitations and primary literature reporting limitations. The identification of so many citations through the reference lists of publications identified by the search engines, i.e., 16 % of all references included, suggests that the search strategies may have been too specific. It is difficult to achieve the optimal balance between sensitivity and specificity, as time and resource constraints limited the number of abstracts that could be screened for inclusion and a number of known articles were not identified by this approach. This was because of relying on authors mentioning the shellfish-borne viral outbreaks in the title, abstract or keywords to enable them to be identified by the search strategy. For example, ProMED reported 84 outbreaks associated with oysters but only 9 were found to be of viral origin; all the others been of bacterial origin.

Articles without abstracts or keywords may not have been identified on the basis of their title alone; for example, the article of McDonnell et al. (1997) referring to overboard dumping of feces during a community outbreak of diarrheal illness. Articles where the place of shellfish food

Table 1 Shellfish-borne viruses implicated in outbreaks from the scientific literature and ProMED reports*

Shellfish-borne outbreaks	No. (%) of outbreaks	
	Scientific literature	ProMED reports
Norovirus	300 (83.7)	8 (88.9)
Hepatitis A virus	46 (12.8)	1 (11.1)
Hepatitis E virus	1 (0.3)	–
Sapovirus	1 (0.3)	–
Astrovirus	2 (0.5)	–
Rotavirus	1 (0.3)	–
Aichi virus	1 (0.3)	–
Enterovirus	1 (0.3)	–
Other viruses	11 (3.0)	–

* Morse et al. 1986, Sekine et al. 1989, Desenclos et al. 1991, Tang et al 1991, Chalmers and McMillan 1995, Kohn et al. 1995, Dowell et al. 1995, Sugieda et al. 1996, McDonnell et al. 1997, Stafford et al. 1997, Christensen et al. 1998, Farley et al. 1998, Leoni et al. 1998, Ng et al. 1999, Wallance et al. 1999, Otsu et al. 1999, Berg et al. 2000, Burkhardt and Calci 2000, Conaty et al. 2000, Godoy et al. 2000, Inouye et al. 2000, Simmons et al. 2001, Umesh et al. 2001, Kingsley et al. 2002, Sanchez et al. 2002, Beuret et al. 2003, Le Guyader et al. 2003, Doyle et al. 2004, Prato et al. 2004, Bon et al. 2005, Chua et al. 2005, Gallimore et al. 2005, Le Guyader et al. 2006, Bialek et al. 2007, David et al. 2007, Sarna et al. 2007, Shieh et al. 2007, Symes et al. 2007, Webby et al. 2007, Nenonen et al. 2008, Pontrelli et al. 2008, Guillois-Becel et al. 2009, Hossen et al. 2009, Le Guyader et al. 2009, Lee et al. 2009, Nenonen et al. 2009, Said et al. 2009, Baker et al. 2010, Dore et al. 2010, Gail et al. 2010, Iizuka et al. 2010, Iritani et al. 2010, Karagiannis et al. 2010, Maalouf et al. 2010, Verhoef et al. 2010, Westrel et al. 2010, Galmés Truyols et al. 2011, Lee et al. 2011, Smith et al. 2011, Wall et al. 2011, Alfano-Sobsey et al. 2012, Lowther et al. 2012

Table 2 Shellfish species implicated in viral outbreaks from the scientific literature and ProMED reports*

Shellfish species	No. (%) of times reported	
	Scientific literature	ProMED reports
Oysters	215 (58.4)	9 (100)
Clams	83 (22.6)	–
Mussels	2 (0.5)	–
Cockles	3 (1.1)	–

* Morse et al. 1986, Sekine et al. 1989, Desenclos et al. 1991, Tang et al 1991, Chalmers and McMillan 1995, Kohn et al. 1995, Dowell et al. 1995, Sugieda et al. 1996, McDonnell et al. 1997, Stafford et al. 1997, Christensen et al. 1998, Farley et al. 1998, Leoni et al. 1998, Ng et al. 1999, Wallance et al. 1999, Otsu et al. 1999, Berg et al. 2000, Burkhardt and Calci 2000, Conaty et al. 2000, Godoy et al. 2000, Inouye et al. 2000, Simmons et al. 2001, Umesh et al. 2001, Kingsley et al. 2002, Sanchez et al. 2002, Beuret et al. 2003, Le Guyader et al. 2003, Doyle et al. 2004, Prato et al. 2004, Bon et al. 2005, Chua et al. 2005, Gallimore et al. 2005, Le Guyader et al. 2006, Bialek et al. 2007, David et al. 2007, Sarna et al. 2007, Shieh et al. 2007, Symes et al. 2007, Webby et al. 2007, Nenonen et al. 2008, Pontrelli et al. 2008, Guillois-Becel et al. 2009, Hossen et al. 2009, Le Guyader et al. 2009, Lee et al. 2009, Nenonen et al. 2009, Said et al. 2009, Baker et al. 2010, Dore et al. 2010, Gail et al. 2010, Iizuka et al. 2010, Iritani et al. 2010, Karagiannis et al. 2010, Maalouf et al. 2010, Verhoef et al. 2010, Westrel et al. 2010, Galmés Truyols et al. 2011, Lee et al. 2011, Smith et al. 2011, Wall et al. 2011, Alfano-Sobsey et al. 2012, Lowther et al. 2012

consumption was only mentioned as a detail in the full text and not in the title, in keywords or in the abstract may have also been missed. In addition, articles that mainly concerned with the methodological issues may have been missed, too.

It was also very difficult to make comparisons between outbreaks on the base of the different types of viruses as there were vast differences in key characteristics of the affected populations. Where reported, there was also substantial variation in case definitions between outbreaks identified; accounts based on self-reported cases had a substantially higher mean number of cases than those requiring a clinical diagnosis or laboratory confirmation and those that did not report the type of case definition used at all had, on average, the largest number of cases. Calculation of attack rate is also likely to have varied by study.

This review also suffered from a lack of reporting of detail. For example, it was difficult to assess the evidence supporting the classification of the outbreaks as foodborne or the degree of association between shellfish and disease given the limited amount of information often provided, particularly in the ProMED reports. A quarter (25 %) of those which provided the number of cases did not report the type of case definition used, i.e., whether they were laboratory-confirmed, clinically diagnosed or self-reported cases. Details of other events thought to be involved in the outbreaks, i.e., the extreme water-related weather, were rarely given. This severely limits the suitability of the results for extrapolation to different circumstances and geographical locations.

Shellfish are consumed in individual or small group settings. It is clear that public awareness through media reports (Davis et al. 1994), aggressive investigation and case finding by authorities (Rippey 1994) can substantially affect both the number of outbreaks identified and the volume of illness reported. Investigations of specific disease outbreaks linked to shellfish consumption have been reported in the scientific literature in many countries; however, few countries systematically collate and report such data through a disease surveillance system. In the UK, for example, collection of epidemiological data for England and Wales is performed by the Public Health Laboratory Service Communicable Disease Surveillance Centre and published periodically (Sockett et al. 1985; Anon 1992; Sockett et al. 1993; Anon 1993; PHLS Viral Gastroenteritis Sub-Committee 1993; Anon 1998). Disease surveillance authorities in the UK (PHLS Viral Gastroenteritis Sub-Committee 1993) and elsewhere (Rippey 1994) recognize that officially reported cases considerably underestimate the actual burden of disease from eating shellfish. For example, until the 1980s up to about 50 outbreaks per decade were documented in the USA. This increased dramatically to 217 outbreaks in the decade 1980–1990 with nearly 7,000 associated cases (Rippey 1994). There are a number of reasons for this, including the absence of mandatory requirements for reporting gastroenteritis and the relatively mild nature of the illness which, although unpleasant, is of short duration and followed by complete recovery with no long-term sequelae. Patients frequently do not present to their doctor and even when they do the illness is not further investigated or reported. Reported incidents, therefore, relate principally to large functions where multiple illnesses are more apparent and where classical statistical correlations between illness and a food vehicle can be made. Individual cases are rarely if ever investigated and do not feature in the disease statistics in any country (Davis et al. 1994; Lees 2000).

The commonly cited rule of William Butler, which recommends eating oysters only during autumn and winter, does not seem to reflect custom (Potasman et al. 2002). Nevertheless, this review suggests that outbreaks of shellfish-borne infectious disease do occur in the winter months. It is interesting to note that UK epidemiological data show a pronounced seasonal effect for illness associated with shellfish with outbreaks predominantly occurring in the winter months (PHLS Viral Gastroenteritis Sub-Committee 1993). Data from the USA also show seasonal variation but disease peaks occur in both late spring and late fall (Rippey 1994). In the UK, norovirus circulation in the community has historically been associated with winter months being known in early literature as "winter vomiting disease." However, circulation in the community is not always consistent with peaks of shellfish-associated gastroenteritis. As an example in the UK during 1995, greatest numbers of norovirus infection were reported during spring and summer months with the fourth quarter being unusually low (Anon, 1996). In the UK, the large majority of oysters are purified (depurated) prior to sale to the consumer. Recent data suggest that the seasonal pattern of shellfish-associated illness in the UK may also be influenced by failure of oysters to clear viral contamination in purification systems during the winter months when shellfish metabolic activity is reduced (Dore et al. 2010). Experience from Japan in 1987–1992 is similar to that of the United Kingdom: most outbreaks occurred during winter, followed by spring (Otsu et al. 1999).

The global distribution of shellfish-borne viral outbreaks as reported in the scientific literature is also likely to be prone to considerable publication bias. A greater proportion of those identified through databases and ProMED searches were in East Asia, followed by Europe, America, Oceania, Australia and North Africa. According to the data provided by the Food and Agriculture Organization of the United Nations, bivalve shellfish are consumed by inhabitants of all continents (Statistical database 2000). Yet, despite this evidence, reports of bivalve-associated infections from Africa are lacking. It appears unlikely that no outbreaks have occurred in the warm climates that prevail in Africa. It is considered that this finding represents underreporting, rather than a lack of bivalve-associated infections (Potasman et al. 2002). The scientific literature is also likely to be dominated by accounts of shellfish-borne disease from higher-income countries, with greater academic and surveillance capacity.

Since the late 1970s with the recognition of viruses as significant agents of infection, increasing numbers of outbreaks were recognized as viral in origin. The scientific literature suggests that, of those shellfish linked to food-borne viral outbreaks, norovirus or hepatitis A virus result in the highest numbers of cases. For example, similarly, between the years 1965 and 1983, of 60 reported outbreaks associated with molluscan shellfish, 22 (37 %) were caused by norovirus, 10 (17 %) by hepatitis A virus and 26 (43 %) were of unknown agents (Sockett et al. 1985). Epidemiological linkage of an outbreak to a particular source is more difficult for some virus infections because of differences in incubation times. For instance, HAV 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. Illnesses because of norovirus and sapovirus are easier to track because of their short 1–2-day incubation period. Norovirus was by far the most common pathogen implicated in outbreaks associated with molluscan shellfish from both the scientific literature and ProMED, which may, in part, reflect the predominance of outbreaks following heavy rain falls and flooding.

However, the symptoms of disease reported in most shellfish-borne outbreaks were similar and were described as "mild" gastroenteritis with clinical features consistent with norovirus gastroenteritis as described in the following. Outbreaks caused by norovirus are characterized by mean incubation periods of 24–48 h, mean illness durations of 12–60 h and a high percentage of patients with diarrhea, nausea, abdominal cramps and vomiting and a lower percentage with fever winter months (Kaplan et al. 1982). This combination of clinical symptoms is highly characteristic for viral gastroenteritis and unlike those reported for enteric infections with bacteria or parasites or for chemical intoxication.

Data on infectious diseases associated with outbreaks of gastroenteritis related to shellfish consumption have also been collated from a variety of sources, for the USA (Richards 1985; Rippey 1994), the UK and elsewhere.

Oysters and clams were responsible for most of these reported cases with soft clams, mussels and cockles only infrequently implicated.

Following review and strengthening of sanitary controls on commercial cooking procedures, shellfish-associated outbreaks markedly decreased (Dore et al. 2010). Outbreaks associated with authorized commercial processors of cooked cockles or mussels have not been reported for a number of years suggesting these improvements were effective. Bacterial causes of infection associated with bivalve shellfish have only occasionally been reported during the last decade (Anon 1998) probably reflecting the success of depuration processes at removal of these contaminants. Of the bivalve species, oysters are now the shellfish vehicle of most concern worldwide.

Where an outbreak is reported, some effort should be made to classify the probable route (or routes) of transmission. This would allow a greater proportion of shellfish-borne outbreaks to be identified and included in systematic analyses. Where the number of cases involved in an outbreak was reported, the case definition used should be clearly stated. If a climatic event is thought to be implicated in a shellfish-borne outbreak, details of how it may have led to contamination of the water should be reported. It is also important to raise awareness of the potential role of such events in shellfish outbreaks, to encourage authors to question explicitly whether such an event occurred prior to the outbreak and if so, to detail it in a structured way.

Conclusions

Shellfish-borne diseases are contributors to global disease burden and mortality. Improving the understanding of the impact that the shellfish consumption has on foodborne disease is an important step toward finding ways to mitigate the risks. At a time, when shellfish production is predicted to increase both the frequency and intensity of shellfish-borne outbreaks in many regions, understanding and reducing the impact of these events is vital to the health of many as well as the growth and development of shellfish production.

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