CHAPTER 10

Epidemiology of Viral Food-borne Outbreaks

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1.0. INTRODUCTION

In 1978, Greenberg et al. (1978) reported serologic evidence that Norwalk or Norwalk-like virus was the likely cause of 8 of a series of 25 outbreaks of acute gastroenteritis of unknown etiology for which acute and convalescent sera had been collected. The outbreaks occurred over a period of 12 years in a variety of settings including cruise ships, schools, nursing homes, and the community. Four years later, Kaplan and colleagues demonstrated that Norwalk virus outbreaks had characteristic clinical and epidemiologic features, that a high proportion of outbreaks with these features were caused by Norwalk-like viruses (now known as noroviruses), and that these accounted for most outbreaks of acute nonbacterial gastroenteritis reported in the United States (Kaplan et al., 1982a, 1982b).

During the ensuing two decades, a variety of diagnostic methods were developed and used, culminating in the widespread use of reverse transcription–polymerase chain reaction (RT-PCR) to detect viral RNA (Atmar and Estes, 2001). Sequencing of PCR products has been extremely valuable for classifying these viruses and establishing genetic relationships between virus strains (Ando et al., 2000). However, although these impressive developments in diagnostic methods have broadened our understanding of the epidemiology of noroviruses, their epidemiology has not fundamentally changed. The types of outbreaks currently making headlines reflect the same patterns that were recognized early on. Whether more rigorous investigation and laboratory confirmation of outbreaks will lead to better outbreak control and public health prevention measures remains to be determined.

Although several groups of viruses may be transmitted through the fecal-oral route, norovirus and hepatitis A virus (HAV) are recognized as the most important human food-borne viruses due to the number of outbreaks and people affected by noroviruses and the potential severity of illnesses caused by HAV (Koopmans and Duizer, 2004). An excellent review of food-borne HAV has recently been published (Fiore, 2004), and this chapter will focus on noroviruses.

2.0. OUTBREAK DETECTION, INVESTIGATION, AND SURVEILLANCE

2.1. Outbreak Detection Methods

Outbreaks of gastrointestinal illness are detected by one of two primary means. The first involves recognizing a pattern of illnesses among persons with a common exposure, such as attending a banquet (Hedberg, 2001). Detecting these outbreaks requires that a number of people who become ill have some reason to discuss their illness with others in their group. This allows the group, *a priori*, to attribute the illnesses to the common event and frequently leads them to report the outbreak to public health officials. The primary implications are that large outbreaks are more likely to be detected, and there is also a bias toward detecting outbreaks involving socially cohesive groups. There is a secondary bias toward detecting outbreaks associated with commercial establishments, as many groups are reluctant to report outbreaks in which it is likely that one or more members of the group is the source.

The dependence of outbreak detection on the size of the outbreak and social cohesion of the group is modified by the agent and its characteristic incubation period. For example, contamination of food by chemical agents or large amounts of staphylococcal enterotoxin may cause a high proportion of exposed persons to become ill (high attack rate), and the illnesses may begin while the event is ongoing. Under these circumstances, outbreak detection is unavoidable.

With noroviruses, illnesses typically begin 24–48 hr after the exposure. This reduces the likelihood of detecting outbreaks in restaurants, where most other patrons are anonymous. Individuals, unaware of similar illnesses among other patrons, may write off their experience as "the flu" or attribute it to a more recently eaten meal. Thus, for "one-time" events, being part of a socially cohesive group greatly increases the likelihood of detecting an outbreak of norovirus. A further implication of the above is that being part of a group with multiple or continuous exposures over a time period that exceeds the incubation period for noroviruses also increases the likelihood of detecting an outbreak. Two settings where this has been clearly demonstrated are cruise ships and nursing homes (Centers for Disease Control and Prevention, 2001).

The second means of detecting outbreaks involves identifying an unusual cluster of cases reported through pathogen-specific surveillance. Because there is no routine clinical laboratory testing for noroviruses, there is no pathogen-specific surveillance for them, such as is conducted for *Salmonella enterica* serotypes or *Escherichia coli* O157:H7. The only food-borne virus for which routine laboratory surveillance is conducted is HAV.

Detection of outbreaks of HAV is greatly complicated by both the length and variability of the incubation period. Not only does this require people to individually remember food exposures 2–6 weeks before onset of their

illness but also requires linking illnesses that could be separated by as much as a month to a common exposure. Even though most persons diagnosed with HAV are interviewed by public health investigators, most interviewers do not attempt to collect detailed food histories. If several cases identify a common restaurant, it may lead to further investigation. However, in many cases the source remains unknown (Fiore, 2004).

2.2. Public Health Investigation of Outbreaks

Outbreaks associated with events and establishments require prompt and thorough investigation to identify the agent, route of transmission, and source of the outbreak (Hedberg, 2001). Identifying the agent is a complex process that involves collecting information about the occurrence of various symptoms, plotting the distribution of case onsets by time, and collecting stool samples to test for the presence of the agent. Because vomiting, fever, and diarrhea commonly occur with many food-borne diseases, diagnosing an individual illness requires specific laboratory testing. The Centers for Disease Control and Prevention (CDC) have incorporated this logic into their criteria for confirming the etiology of an outbreak (Olsen et al., 2000). Thus, for an outbreak to have a confirmed etiology, two or more cases have to be individually confirmed by laboratory testing.

Taken on face value this seems a reasonable measure. However, the practical implication is that it reduces the effort to identify the agent into one of obtaining stool samples and getting them tested. Unfortunately, in many outbreak investigations, laboratory testing may not be adequate to identify the agent (Hedberg, 2001). In practical terms, this has discouraged investigations of outbreaks with a suspected viral etiology (Bresee et al., 2002). Thus, many outbreaks may be detected and reported to local public health officials but never investigated because of the inability to confirm the agent by laboratory testing. This has created a negative feedback loop in which outbreaks do not get investigated because no agent can be identified. Thus, the outbreaks do not get tabulated in official summaries and do not appear to contribute to the overall burden of illness. One measure of this impact was a survey of public health personnel conducted in Tennessee (Jones and Gerber, 2001). As part of a training program on food-borne disease investigations, public health workers were asked to identify the top three causes of food-borne illness. Only 5% listed Norwalk-like viruses, even though they are estimated to cause two thirds of food-borne illnesses caused by known food-borne agents (Mead et al., 1999).

Careful evaluation of clinical and epidemiological characteristics of outbreaks can allow rapid identification of agents in the absence of laboratory testing and can help guide the public health laboratory to conduct appropriate tests to confirm the presence of noroviruses. Hall et al. (2001) demonstrated that 340 of 712 (48%) outbreaks, for which no pathogen was isolated, fit a Norwalk-like virus epidemiologic profile. During this time period, only seven laboratory-confirmed outbreaks of Norwalk-like virus had been reported.

Table 10.1 Epidemiologic Criteria for Rapid Classification of Norovirus Outbreaks

Source	*Criteria*	*Application*
Kaplan et al., 1982a	1. Stool cultures negative for bacterial pathogens 2. Median incubation period 24–48 hr 3. Median duration of illness 12–60 hr 4. Vomiting in >50% of patients	Criteria as written are appropriate for retrospective evaluation of outbreaks. For rapid prospective evaluation, the incubation period and percent of patients with vomiting are the key determinants.
Hedberg and Osterholm, 1993	1–3. Same as Kaplan's 4. Percent of patients with vomiting > percent of patients with fever	For rapid prospective evaluation, the incubation period and the ratio of patients with vomiting and fever are the key determinants. Because vomiting is less common among outbreaks involving adults, the ratio of vomiting to fever increases the sensitivity of the criteria.

It is frequently claimed that the epidemiology of noroviruses is poorly understood because of a long-standing lack of diagnostic assays (Widdowson et al., 2004), which is certainly true from the standpoint of the molecular epidemiology of virus transmission through populations. However, the availability of a relatively specific epidemiologic profile (Table 10.1) more than 20 years ago should have facilitated national surveillance for norovirus outbreaks (Kaplan et al., 1982a; Hedberg and Osterholm, 1993). A model for what such a system might have looked like could be the state of Minnesota, where the use of epidemiologic criteria to define outbreaks of Norwalk-like viruses was initiated in 1982. From 1981 to 1998, Norwalk-like viruses were the most common cause of food-borne disease outbreaks, accounting for 41% of all food-borne outbreaks reported in Minnesota (Deneen et al., 2000).

The other benefit of using epidemiologic profiles is that it helps train public health investigators to rapidly and carefully collect and analyze detailed information as a routine measure. As a consequence, epidemiologists are better able to assist laboratory staff and environmental health specialists in conducting their evaluations. Rapid epidemiologic investigation of outbreaks requires the ability to interview large numbers of people quickly. Conducting these interviews may be a rate-limiting step for many local public health agencies with limited resources. To address this problem, the Minnesota Department of Health hires public health students to serve as its primary workforce (known as "Team Diarrhea") to conduct interviews. Rapid epidemiologic investigation may also be facilitated by the use of the Internet to send and receive questionnaires (Kuusi et al., 2004).

2.3. Outbreak Surveillance Systems

In the United States, outbreak surveillance usually begins with the detection and investigation of the outbreak at the local level (Olsen et al., 2000). Jurisdiction for investigating an outbreak may depend on the outbreak setting. For example, an outbreak in a restaurant may be investigated by the local environmental health agency that licenses and inspects the establishment. In contrast, an outbreak in a nursing home may be referred to nursing home regulators at the state health department for investigation. In most states, the state health department is responsible for coordinating outbreak investigations across jurisdictions and for compiling and disseminating outbreak reports. On a national level, CDC maintains surveillance only for outbreaks of food-borne and waterborne illnesses (Widdowson et al., 2004). This division of labor and information relating to surveillance of outbreaks in the United States makes it very difficult to develop a comprehensive picture of the public health impact of noroviruses.

In Europe, there is considerable variation in national surveillance systems (Lopman et al., 2003a), and efforts have been made to assess and harmonize surveillance methods (Koopmans et al., 2003). In most countries, outbreaks of gastroenteritis are investigated without regard to outbreak size or possible mode of transmission. Thus, these countries provide the most useful surveillance data on the overall impact of noroviruses. However, there is considerable variation between countries in the use of clinical criteria and laboratory confirmation for inclusion of outbreaks into surveillance databases (Lopman et al., 2003a). Denmark and France primarily investigate outbreaks that appear to be food-borne from the onset. These surveillance systems are more comparable to those in the United States.

3.0. MOLECULAR EPIDEMIOLOGY

The cloning and characterization of the Norwalk virus genome led to the development of RT-PCR, gene sequencing, molecular characterization of noroviruses, and the molecular epidemiology of norovirus outbreaks (Jiang et al., 1990; Ando et al., 1995; Vinje and Koopmans, 1996; Noel et al., 1999). In particular, it has become clear that the noroviruses are genetically diverse viruses, that multiple strains circulate simultaneously, and that individual strains may predominate over a given time period (Hale et al., 2000; Green et al., 2002; Fankhauser et al., 2002; Gallimore et al., 2004b; Lau et al., 2004; Vipond et al., 2004). Furthermore, the emergence of new strains may occur on a global basis accompanied by the increased occurrence of outbreaks in a variety of settings (Noel et al., 1999; Lopman et al., 2004; Widdowson et al., 2004).

It has long been recognized that norovirus outbreaks occur in the context of more widespread illness in the community (Hedberg and Osterholm, 1993). It has also been demonstrated that outbreaks and sporadic cases may be caused by the same virus strains in the community (Buesa et al., 2002;

Gallimore et al., 2004a; Lau et al., 2004). However, the rapid dissemination of new strains leaves open the question of primary mechanisms for their rapid spread (Noel et al., 1999; Lopman et al., 2004; Widdowson et al., 2004). Food-borne outbreaks involving transmission over wide geographic areas have been documented (Ponka et al., 1999; Berg et al., 2000; Anderson et al., 2001; Koopmans et al., 2003). However, extensive investigation of outbreaks on multiple cruise ships caused by identical strains has failed to identify a common source (Widdowson et al., 2004). Furthermore, people infected in one outbreak setting have been identified as the source for outbreaks in other areas (Fretz et al., 2003; Widdowson et al., 2004). Thus, it remains likely that noroviruses, like HAV and rotaviruses, are primarily spread from person-to-person, with outbreaks of food-borne disease serving to periodically amplify transmission (Parashar et al., 1998; Marshall et al., 2003; Fiore, 2004).

The molecular epidemiology of norovirus outbreaks also suggests that norovirus genogroups may differ in pathogenicity or have genogroup-specific characteristics that affect the dynamics of transmission in particular settings. In both the United States and United Kingdom, GII/1,4 strains were more common in nursing home outbreaks than in other settings (Fankhauser et al., 2002; Gallimore et al., 2004a). Conversely, GI strains are more common in other settings. For example, Gallimore et al. (2003) found that GI strains accounted for 38% of cruise ship outbreaks but for <10% of outbreaks in nursing homes or other institutional settings in the United Kingdom. These epidemiologic patterns may be the result of a combination of host, virologic, and environmental factors (Lopman et al., 2003b). Molecular characterization of noroviruses implicated in outbreaks across all settings will be necessary to address these questions.

4.0. MODES OF TRANSMISSION

Outbreaks of norovirus have been reported in virtually every type of institutional and food service setting and in conjunction with various types of water systems (Centers for Disease Control and Prevention, 2001). Most outbreaks appear to be a manifestation of fecal-oral route of exposure, with contaminated food or water serving as a vehicle. However, aerosol transmission of viruses likely contributes to outbreaks in many institutional settings, and environmental contamination has been implicated as well (Cheesebrough et al., 2000; Evans et al., 2002; Kuusi et al., 2002; Marks et al., 2003). The dynamics of person-to-person spread are largely unknown but likely involve combinations of the above.

4.1. Food-borne Disease Transmission

Food-borne transmission of noroviruses occurs because of human fecal contamination of a raw or ready-to-eat food item. This can occur at any point along the food chain; in production, during processing, or at the point of food

service. Much of the early literature on food-borne disease transmission of noroviruses focused on contaminated shellfish (Hedberg and Osterholm, 1993). These outbreaks occurred because oysters, in particular, were harvested from waters contaminated by human sewage and consumed raw. Although they continue to have the potential to cause widespread transmission of noroviruses (Berg et al., 2000; Simmons et al., 2001; Koopmans et al., 2003), their relative importance was almost certainly inflated by a bias on the part of public health officials to investigate such outbreaks.

In Minnesota, Norwalk-like viruses accounted for 41% of confirmed food-borne outbreaks reported from 1981 to 1998 (Deneen et al., 2000). However, none of these outbreaks was attributed to shellfish. Fankhauser et al. (2002) identified contaminated food as the cause of 57% of U.S. outbreaks during 1997–2000 in which the source of transmission was investigated; none was related to oysters.

Fresh fruits and vegetables are also susceptible to contamination in the field, at harvest, and during processing. Such contamination has been responsible for large outbreaks of HAV due to produce items ranging from blueberries (Calder et al., 2003) to green onions (Centers for Disease Control and Prevention, 2003b). However, an international outbreak of norovirus associated with frozen raspberries stands out as an exceptional occurrence (Ponka et al., 1999). The lack of laboratory testing to identify specific norovirus strains has limited the ability of investigators to link separate outbreaks to a potential common source (Anderson et al., 2001; Koopmans et al., 2003).

Most food-borne transmission appears to occur as a result of contamination of foods at the point of service. In Minnesota, 62% of confirmed food-borne outbreaks of viral gastroenteritis were likely the result of contamination of foods by contact with bare hands (Deneen et al., 1999). Although such contamination in most restaurant settings is due to food workers, contamination of foods by patrons has also resulted in outbreaks (Marshall et al., 2001).

Food-borne transmission is the most common mode of transmission for outbreaks that occur in restaurants and catered events (Fankhauser et al., 2002; Lopman et al., 2003b). Food-borne transmission also occurs in institutional settings such as schools, nursing homes, camps, and cruise ships. However, multiple modes of transmission occur in most of these settings, and it is frequently difficult to distinguish the role of food-borne disease transmission. It is hoped that the broader use of sensitive assays to both confirm and subtype norovirus strains will result in better understanding of the dynamics of transmission in these settings (Parashar and Monroe, 2001).

4.2. Waterborne Disease Transmission

Most waterborne disease outbreaks have resulted from fecal contamination of private wells and untreated community or noncommunity water systems (Hedberg and Osterholm, 1993; Centers for Disease Control and Prevention,

2001). The route of transmission for most waterborne outbreaks has been identified as a result of epidemiologic investigations and environmental assessments of the facilities. However, isolation of norovirus from water has been uncommon (Carique-Mas et al., 2003; Parshionikar et al., 2003). Waterborne transmission has also occurred on cruise ships, either because of the storage and use of untreated water or because of cross-connections in the ship's plumbing (Gallimore et al., 2003; Widdowson et al., 2004).

Outbreaks of viral gastroenteritis have been associated with swimming in lakes and swimming pools, usually as a result of the presence of one or more infected persons contaminating a crowded swimming area (Hedberg and Osterholm, 1993). Exposure to a recreational water fountain was implicated as the source of an outbreak in The Netherlands (Hoebe et al., 2004). The same norovirus identified from cases was also identified in a water sample from the fountain. Similarly, taking showers with contaminated water has been implicated as an additional route of waterborne transmission in Italy and Norway (Boccia et al., 2002; Nygard et al., 2004).

4.3. Airborne and Environmental Transmission

Most enteric viruses are transmitted by a fecal-oral route, which is reflected in the epidemiologic pattern of outbreaks reported (Fankhauser et al., 2002; Lopman et al., 2003b; Fiore, 2004). Because noroviruses are also expelled in vomit, the aerosolization of vomitus may create opportunities for widespread transmission and environmental contamination with noroviruses that would not occur with HAV (Centers for Disease Control and Prevention, 2001; Fiore, 2004). However, assessing the public health importance of airborne and environmental transmission has been difficult, as such transmission almost always occurs in settings such as cruise ships, nursing homes, and schools where food-borne, waterborne, or person-to-person transmission may also occur.

Evidence for environmental transmission of noroviruses is supported by findings such as the occurrence of illness among hotel employees who did not eat at the hotel during the course of an outbreak at the hotel (Love et al., 2002). Evidence for airborne transmission of noroviruses is supported by findings such as an increased risk of illness among school children after a vomiting event in their classroom (Marks et al., 2003). An increased risk of illness associated with showering in waterborne outbreaks also suggests airborne transmission (Boccia et al., 2002; Nygard et al., 2004).

More definitive evidence for airborne and environmental transmission was an outbreak that occurred in a concert hall after a concert-goer vomited in the auditorium and adjacent toilet (Evans et al., 2002). Illness occurred in 8 of 15 groups of schoolchildren who attended the next day, and risk of illness was associated with whether the group was seated near where the vomiting event occurred. In a protracted outbreak at a hotel, Norwalk-like virus was identified by RT-PCR in multiple environmental swabs (Cheesbrough et al., 2000). Samples collected from areas that were directly contaminated by

vomit were more likely to be positive. However, evidence of broader environmental spread was also detected.

Even when noroviruses can be detected in environmental samples, it is necessary to conduct a thorough epidemiological investigation to interpret the significance of the findings. In a prolonged outbreak of Norwalk-like virus at a rehabilitation center in Finland, more than 300 guests and staff members became ill (Kuusi et al., 2002). No food or activity at the center could be associated with illness, and food and water samples tested negative for Norwalk-like viruses. However, Norwalk-like viruses identical to those from patients were detected in three environmental samples. In the context of these findings, it appears that environmental contamination was important to the prolonged occurrence of this outbreak.

4.4. Person-to-Person Transmission

Secondary transmission of noroviruses to household members has been regularly observed after food-borne and waterborne outbreaks (Centers for Disease Control and Prevention, 2001). Such transmission also contributes to the complexity of outbreaks in institutional settings where introduction of the virus through a food vehicle can result in extended person-to-person transmission among persons with continuous or repeated exposures. An unusual example of this is the spread of Norwalk-like virus in 30 daycare centers that shared a common caterer (Gotz et al., 2002). Consumption of a pumpkin salad was implicated as the source for the first cases that occurred with a mean incubation period of 34 hr. The primary attack rate was 27%. The secondary attack rate among daycare and household contacts was 17%. The incubation period for secondary transmission was estimated to be 52 hr (Gotz et al., 2001). Risk factors for spread into households included the occurrence of vomiting and having a child as the primary case.

Person-to-person transmission is frequently identified as the primary mode of transmission in nursing homes, schools, and other institutional settings (Fankhauser et al., 2002; Lopman et al., 2003b). However, this is generally the reflection of an epidemiologic picture in which there is no obvious point source of exposure and cases occur over a prolonged time period. In only a few of these settings do public health investigators actively identify the patterns of personal contact that would be necessary to establish this mode of transmission. In all likelihood, what gets labeled as person-to-person transmission actually represents a complex series of exposures that may result from airborne transmission of vomitus as well as contamination of food, water, and environmental surfaces in the common residential setting (Miller et al., 2002). The occurrence of vomiting as a risk factor for secondary transmission suggests that much of this may be due to undocumented airborne and environmental transmission (Gotz et al., 2001). From a public health standpoint, distinction between direct personal contact and environmental contamination could have implications for the emphasis that is put on specific control measures.

5.0. PREVENTION AND CONTROL

Reducing food-borne transmission of hepatitis A depends on food-handler hygiene and providing pre-exposure prophylaxis to persons at risk of infection. Transmission of HAV will continue to decline with routine vaccination of persons at risk for HAV infection (Fiore, 2004). Prevention and control activities for norovirus transmission need to be targeted to the primary transmission routes, which in turn are dependent on setting (Table 10.2). Untreated community water systems are susceptible to contamination that can lead to large common source outbreaks. Although noroviruses are relatively resistant to chlorine, routine chlorination and filtering of drinking water systems appears to be highly effective at preventing waterborne outbreaks (Centers for Disease Control and Prevention, 2001).

Harvesting shellfish from sewage contaminated waters can lead to large and widespread food-borne outbreaks. Although oysters are not harvested from beds known to be contaminated by municipal sewage outflows, sewage contamination from individual boats can be harder to prevent and track (Simmons et al., 2001). Fresh produce fields and the use of water to cool produce (hydrocooling) at harvest may be similarly susceptible to contamination from human sewage. The development and use of good agricultural practices (GAP) should help prevent transmission by this route.

In restaurant settings, infected food-handlers present the greatest risk of transmission. To reduce the risk of a food-borne outbreak, restaurant managers need to train their workers in proper food-handling techniques and encourage frequent hand-washing. In addition, managers should monitor illnesses in staff and exclude ill food-handlers from working in the restaurant.

Table 10.2 Primary Transmission Routes for Noroviruses by Setting and by Characteristics of the Settings

Setting	*Primary Transmission Route*	*Characteristics of the Setting That Favor Transmission Route*
Facility or community with untreated water system	Waterborne	Fecal contamination of well or water system.
Restaurants	Food-borne	Transient customer base with limited opportunities for environmental contamination and repeated exposures. Resident food workers provide extended source of contamination during outbreaks.
Institutional	Person-to-person, airborne, and environmental	Resident population with many opportunities for environmental contamination and repeated exposures.

Such active managerial control is possible only if managers know what is going on in the restaurant and are able to initiate appropriate control measures, although it probably is not possible to prevent all outbreaks of viral gastroenteritis. Just as with HAV, outbreaks will occasionally occur even when it appears that proper procedures are being followed (Centers for Disease Control and Prevention, 2003a).

In the event of illness occurring among food workers, or if patrons become ill at the restaurant, managers should make sure that all surfaces contaminated by feces, vomit, or hands are cleaned and disinfected thoroughly. If it appears that an outbreak of norovirus is occurring in the community, it may be necessary to modify menus to limit potential for customers to contaminate food (e.g., salad bars), or for food handlers to contaminate ready-to-eat foods. In the event of an outbreak at the restaurant, ill foodworkers should be excluded until they are free of symptoms for 72 hr. If it appears that there is an ongoing risk of transmission to patrons, restaurants should close for 72 hr to allow workers to recover and thoroughly clean and disinfect the establishment (Hedberg and Osterholm, 1993).

Institutional settings, particularly hospitals, nursing homes, and cruise ships, represent the greatest challenge to control norovirus transmission. In such settings, it seems reasonable to encourage frequent hand-washing, exclude ill food workers, clean and disinfect surfaces contaminated by feces or vomit, monitor illnesses in residents and staff, and implement control measures at first sign of the outbreak, including isolation of ill residents, exclusion of ill staff, and aggressive cleaning and disinfection (Centers for Disease Control and Prevention, 2001; McCall and Smithson, 2002; Lynn et al., 2004).

In practice, however, it may be difficult to apply infection control guidelines sufficient to prevent transmission (Miller et al., 2002; Kuusi et al., 2002; Khanna et al., 2003). The challenge in preventing outbreaks on cruise ships is even greater with each cruise bringing a new cohort of passengers representing potential sources of exposure as well as a population at risk from food-borne, waterborne, airborne, and environmental infection (Widdowson et al., 2004).

6.0. PUBLIC HEALTH IMPORTANCE

The landmark paper by Mead et al. (1999) on the burden of food-borne illness did much to establish the public health importance of noroviruses in the United States. For the first time, it was recognized that noroviruses are the leading cause of food-borne illness, accounting for 67% of food-borne illnesses caused by known etiologies; more than 9,000,000 infections with 20,000 hospitalizations and 124 deaths annually. In contrast, while the severity of illness caused by HAV is greater, there are only 4,000 cases with 90 hospitalizations and 4 deaths per year caused by HAV in the United States (Mead et al., 1999). Publication of these estimates has served to stimulate

public health interest in surveillance for outbreaks caused by norovirus. In its wake, sensitive diagnostic assays are being widely adopted for use by public health laboratories.

Because of the absence of systematic surveillance for noroviruses in the United States, Mead's estimates were based largely on studies conducted in The Netherlands. Long-standing surveillance for outbreaks in the United Kingdom also presents a broader picture of the impact of norovirus. From 1992 to 2000, 1,877 norovirus outbreaks were reported in England and Wales (Lopman et al., 2003a). Of these, 40% occurred in hospitals and 39% occurred in residential facilities. Because these settings include high proportions of persons at greater risk for serious illness or death, the occurrence of these outbreaks in these settings presents a great public health challenge. Even though food-borne disease surveillance systems in the United States do not typically include reports of outbreaks in these settings, norovirus has been established as the leading cause of outbreaks of gastroenteritis in nursing homes in the United States (Green et al., 2002).

Since the discovery and characterization of Norwalk virus, noroviruses have been demonstrated to be the most frequent known cause of food-borne illness. Furthermore, most illnesses caused by noroviruses are transmitted through other routes, which complicate prevention and control efforts. Although much has been learned about the molecular epidemiology of noroviruses during the past 20 years, this has not yet been translated into more effective prevention and control strategies. More vigorous surveillance and control measures are needed across the public health system.

7.0. SUMMARY AND CONCLUSIONS

Noroviruses are the most common known cause of food-borne illness and outbreaks of food-borne disease in the United States. The clinical and epidemiologic characteristics of these outbreaks were characterized in the early 1980s, but the lack of sensitive diagnostic tests led to their systematic underreporting. The recent development and widespread availability of PCR-based methods throughout the public health laboratory system in the United States has led to a growing awareness of the burden of illness caused by these viruses. Sequencing of PCR gene products is shedding new light on the epidemiology of noroviruses, transmission routes, and global distributions. However, despite these recent advances, our understanding of norovirus epidemiology, prevention, and control is not fundamentally different than it was 20 years ago.

Prevention of norovirus outbreaks relies on the application of infection-control principles: education, surveillance, isolation, and disinfection. Application of these principles needs to be institutionalized throughout the hospitality industry. Encouraging proper hand-washing and excluding ill staff are cornerstones for this effort. The greatest challenge for food service operators is and will continue to be monitoring and managing illnesses among

food workers. Finally, despite the increasing availability of diagnostic tests, confirmation of norovirus infections still requires time and effort in obtaining and transporting the sample, running the test, and interpreting the results. Thus, prompt and effective response to norovirus outbreaks cannot depend on laboratory confirmation but should be initiated at the first sign that the outbreak appears consistent with the epidemiology of norovirus.

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